Egegik, Alaska
Wind Power Feasibility Study

Google Earth image of Egegik

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This feasibility study report was prepared by V3 Energy, LLC under contract to Lake and Peninsula Borough to assess the technical and economic feasibility of installing wind turbines in Egegik, Alaska. This analysis is part of a renewable energy project funded by the Alaska Energy Authority through the Renewable Energy Fund.

Contents

Introduction

Lake and Peninsula Borough was awarded a Renewable Energy Fund grant from the Alaska Energy Authority (AEA) in 2013 to complete resource assessment and feasibility work for possible development of wind power in the community of Egegik. The City of Egegik is the electric utility for the community.

Executive Summary

Egegik has a superior wind resource and at first glance excellent potential for wind power, but it is a small community with low electric load demand during autumn, winter and spring when the Coffee Point Seafoods fish processing plant is not operating. The community may be experiencing a decline of its permanent population due to recent closure of the community school and the documented gradually decreasing load demand over the past few years. But, during the summer fish processing season, Egegik experiences a rapid and dramatic growth in population and energy usage.

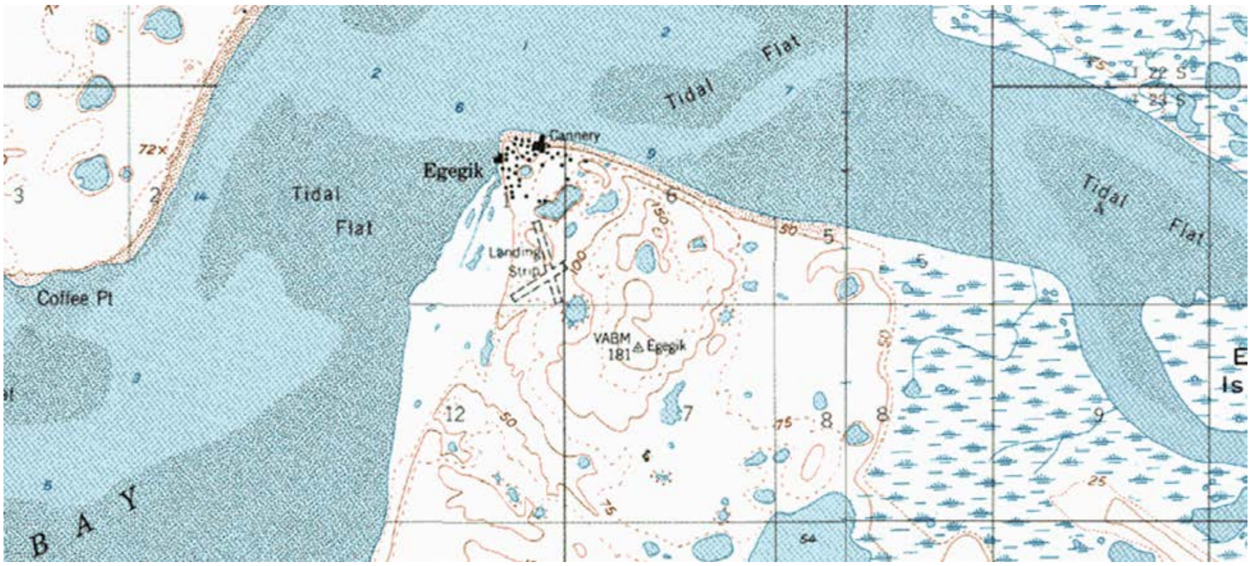
Wind-diesel system modeling suggests that Egegik's powerplant, installed new by Alaska Energy Authority in 2013, is oversized for wind power. During the non-fish processing months, the margin between minimum load of its smallest diesel generator and the often very modest load demand is insufficient to accommodate wind power. But, modeling also suggests that replacing one of the diesel generators with a smaller unit increases this margin sufficiently to make wind power potentially viable for the community. With this, it appears that wind power of approximately 50 kW capacity, combined with a 101 kW diesel generator, may present a solution for Egegik and is recommended for further evaluation and consideration.

Village of Egegik

Egegik is located on the south bank of the Egegik River on the Alaska Peninsula, 100 miles southeast of Dillingham and 326 air miles southwest of Anchorage. Egegik is incorporated as a 2nd class city in the Lake and Peninsula Borough with 85 permanent residents, but its population increases very significantly during early and mid-summer when the Coffee Point Seafoods salmon processing plant is operational. Egegik falls within the southwest climate zone, characterized by persistently overcast skies, high winds, and frequent cyclonic storms.

According to anthropologists, settlement of the Bristol Bay region first occurred over 6,000 years ago. Yup'ik Eskimos and Athabascan Indians jointly occupied the area, while Aleuts arrived in later years. The first recorded contact by non-Natives was with Russian fur traders between 1818 and 1867. The village was reported by Russians in 1876 as a fish camp called "Igagik" (meaning "throat"). Local people would travel each year from Kanatak on the gulf coast through a portage pass to Becharof Lake and then hike or kayak on to the Egegik Bay area for summer fish camp. In 1895, an Alaska Packers Association salmon saltery was established at the mouth of Egegik River, and a town developed around the former fish camp. During the influenza outbreaks beginning in 1918, Native Alaskans from other villages moved to Egegik to isolate themselves from the disease. During World War II, men from Egegik were enlisted to help build the King Salmon Airport, with many subsequently serving in Dutch Harbor and elsewhere. Egegik later grew into a major salmon processing and production port. Egegik incorporated as a second-class city in 1995. [1]

Topographic map of Egegik and vicinity



Google Earth image of Egegik (view SSE)

[1] Community data obtained from State of Alaska DCCED Community and Regional Affairs website

Wind Resource

A 34 meter high NRG Systems, Inc. tubular-type meteorological (met) tower was installed in Egegik in an open area of Becharof Corporation land on a hill approximately 2,200 ft. due east of the Egegik city office. It was operational for 24 months, from late August 2014 to early September 2016.

The wind resource measured at the Egegik met tower site is excellent with a mean annual wind speed of 7.43 m/s and a wind power density of 516 W/m^2 at 34 meters above ground level. In all respects, the Egegik wind resource is highly suitable for wind power development.

A complete wind resource assessment report may be found in Appendix A of this feasibility study.

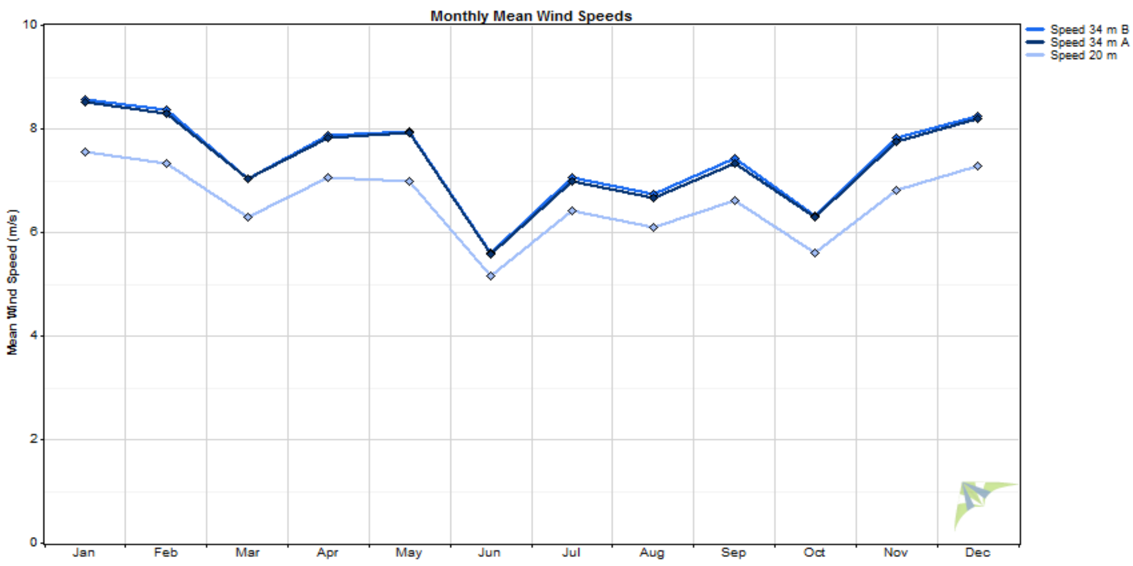
Elim met tower data synopsis

Data dates	8/20/2014 to 9/03/2016 (24.5 months)
Wind speed mean, 34 m, annual	7.43 m/s (16.6 mph)
Wind power density mean, 34 m	516 W/m^2
Wind power class	Class 5 (excellent)
Max. 10-min wind speed	32.6 m/s
Maximum 2-sec. wind gust	41.1 m/s (91.9 mph), December 2015
Weibull distribution parameters	k = 1.92, c = 8.34 m/s
Wind shear power law exponent	0.216 (moderate shear)
Surface roughness	0.28 meters (agricultural land with tall hedgerows)
IEC 61400-1, 3rd ed. classification	Class II-C (possibly Class III-C)
Turbulence intensity, mean (at 34 m)	0.104 (at 15 m/s)
Calm wind frequency (at 34 m)	19% (< 4 m/s)

Measured Wind Speeds

During the measurement period, annual mean winds at the test site measured 7.43 m/s, which is very good indeed for wind power development. The one drawback though is that early summer winds in Egegik reach as seasonal low in June, which coincides with the high summer load demand.

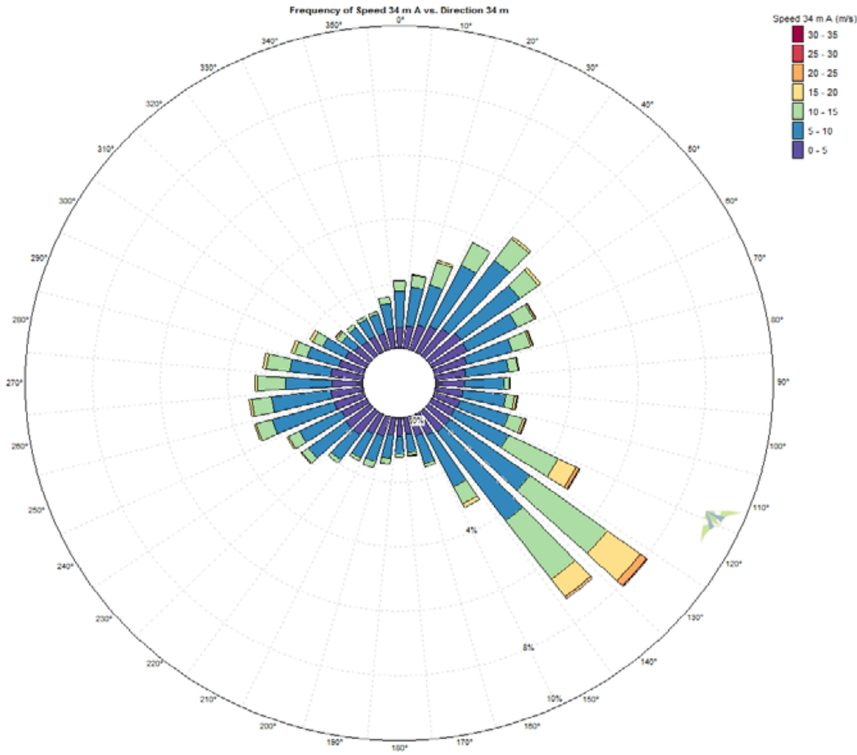
Egegik met tower measured wind speeds



Wind Roses

Wind frequency rose data indicates that winds at the Egegik met tower site are primarily southeasterly, with northeasterly and westerly winds frequent as well. The magnitude of the wind sector "pie" slices indicate that the strongest winds are southeasterly.

Egegik wind rose



WAsP Wind Flow Model

WAsP (Wind Atlas Analysis and Application Program) is a PC-based software designed to estimate wind resource and power production for individual wind turbines and/or wind turbine farms. WAsP was used to predict wind turbine performance at selected locations in Elim.

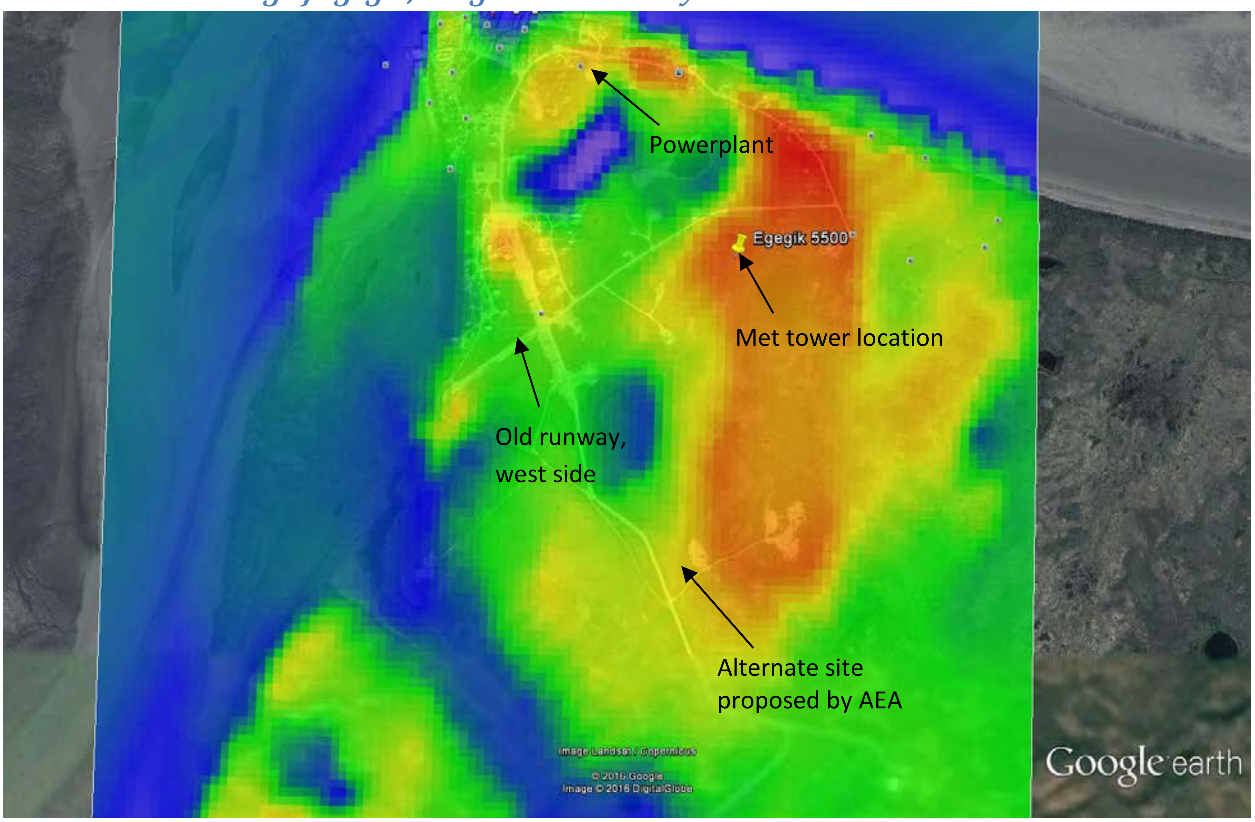
Orographic Modeling

WAsP modeling begins with import of a digital elevation map (DEM) of the subject site and surrounding area and conversion of coordinates to Universal Transverse Mercator (UTM). UTM is a geographic coordinate system that uses a two-dimensional Cartesian coordinate system to identify locations on the surface of Earth. UTM coordinates reference the meridian of its zone (60 longitudinal zones are further subdivided by 20 latitude bands) for the easting coordinate and distance from the equator for the northing coordinate. Units are meters. Elevations of the DEMs are converted to meters (if necessary) for import into WAsP software.

A met tower reference point is added to the digital elevation map, wind turbine locations identified, and a wind turbine(s) selected to perform the calculations. WAsP considers the orographic (terrain) effects on the wind, plus surface roughness variability and obstacles if added, and calculates wind flow increase or decrease at each node of the DEM grid. The mathematical model, although robust, has several limitations, including an assumption that the wind regime at the turbine site is the same as at the met tower reference site, prevailing weather conditions are stable over time, and the surrounding terrain at both sites is sufficiently gentle and smooth to ensure laminar, attached wind flow. The version of WAsP software used for this analysis is capable of modeling turbulent wind flow resulting from sharp terrain features such as mountain ridges, canyons, shear bluffs, etc., but only by accessing supercomputers on the DTU campus in Roskilde, Denmark. Egegik terrain, however, is conducive to laminar air flow.

The general vicinity of Egegik is comprised of mildly undulating to flat terrain without forest cover and with large expenses of water, both river and bay. Nearest Egegik itself though, a 55 meter (180 ft.) elevation extended hill complex comprises the high terrain and most prominent landscape feature. The met tower was located on the high point of the northern lobe of the hill complex. Note that a GCI cellular communications tower is located on the high point of the southern lobe. Modeling indicates that the highest winds in Egegik, as one would expect, are found on the hill complex. The distinct blue-to-red color gradation in the WAsP overlay image below implies more wind variation that actually exists. The measured wind resource is very good and because the met tower/GCI tower hill is not especially high and given the mild topographic relief of the area, the wind resource does not vary appreciably across Egegik.

WAsP wind modeling of Egegik, Google Earth overlay



Wind Turbine Project Site Options

The Egegik met tower location, which is Becharof Corporation land, is an obvious site option for wind turbines from a wind resource perspective, but one drawback of this site is the lack of electric power distribution along the unnamed access road (connected the airport road to Dry Lake Road). Existing distribution is routed to a residence on the south side of the unnamed access road and along Dry Lake Road, but not in-between. Should this site be developed, a distribution connection either direction would be required.

An alternate site option suggested by Alaska Energy Authority is the intersection of the airport access road and GCI communications tower access road, as noted in the map above. This site has the considerable advantage of existing electric power distribution along the access roads and per the WAsP wind flow modeling analysis, the wind resource in this location is nearly as robust as at the met tower site. A disadvantage though is that this site is Native Allotment land. Native Allotment designation does not prevent development, but is a complicating factor. A possible site variation would be across (west side) the airport access road, which from review of land ownership maps, does not appear to be Native Allotment land. The following table illustrates the modeled wind resource at a few wind turbine site options that could be considered.

Two other possible site options are in the laydown yard immediately behind the powerplant and the west side runway of the old airport. Although the met tower site models as the highest wind resource of the four, the three other sites are very good as well, color-coding of the preceding Google Earth graphic notwithstanding. Any of the four could be chosen and satisfactory wind turbine performance can be expected.

Wind resource site options

Site	Wind Speed (m/s)	Power Density (W/m^2)
Met Tower Site	7.47	510
Alternate Site	7.23	468
Powerplant	7.23	459
Old runway, west	7.01	421

Egegik Electrical Power System

The Egegik power system is comprised of a new (installed and commissioned in summer 2013) modular power plant equipped with four diesel generators: three 210 kW capacity John Deere 6090AFM75 and one 400 kW capacity Scania DI13075M. All four generators are equipped with marine manifolds for enhanced jacket water heat recovery capability. The aggregate generation capacity of 1,030 kW is significantly large for such a small community, but note that the powerplant apparently was sized to serve the local Coffee Point Seafoods fish processing plant for the five to six weeks in June and July when commercial salmon processing activities require significant power. It appears though, that this service has never occurred and that Coffee Point Seafoods self-powers its largest industrial loads (refrigeration, line activities, etc.) with its own diesel generator power plant.

The City of Egegik supplies some auxiliary loads to Coffee Point Seafoods during the peak power demand period, which is reflected in increased power demand from late May through late July (this includes the shoulder weeks of ramp-up and shut-down of the fish plant), but the additional power demand of approximately 100 kW is still quite small compared to the generation capacity of the powerplant. In fact, it uncommon for the Egegik power plant load demand during June and July to even require two 210 kW generators to be online, let alone require use of the 400 kW Scania generator.

Note that a minimum 20% sustained diesel engine loading is presumed for this feasibility study. For the smaller John Deere 210 kW engines, this equates to 42 kW. Alaska Energy Authority though considers 20% loading as very minimal and prefers a higher minimum diesel loading of 30%, which would equate to 63 kW for the John Deere's. Diesel engine loading can of course drop below 20% when necessary, but sustained low load operations is not recommended by diesel manufacturers, suppliers and power system operators due to low efficiency and potential problems such as wet stacking[2].

Diesel Generators

The Egegik power plant is equipped with four diesel generator models as detailed below.

Egegik powerplant diesel generator configuration

Bay	Diesel Engine	Electrical Rating	Fuel effic. at 75% load[3]
1	John Deere 6090AFM75 (marine)	210 kW	13.5 kWh/gal
2	John Deere 6090AFM75 (marine)	210 kW	13.5 kWh/gal
3	Scania DI13 075M (marine)	400 kW	15.3 kWh/gal
4	John Deere 6090AFM75 (marine)	210 kW	13.5 kWh/gal

Electric Load

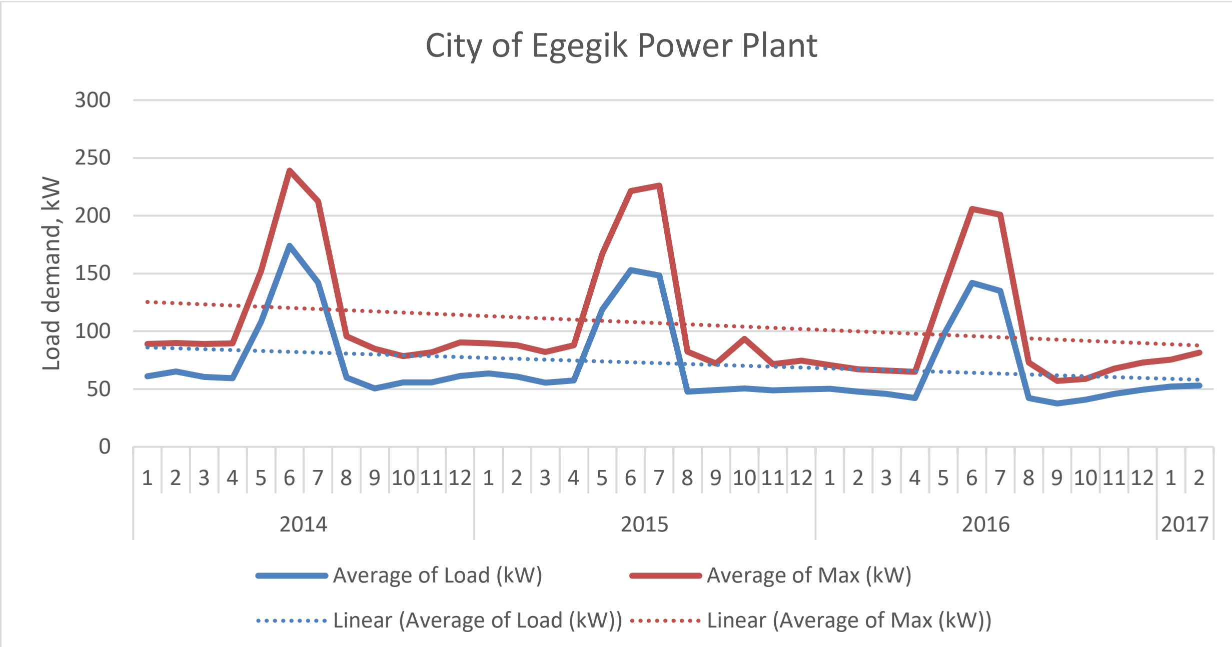
Egegik electric load was obtained from the City of Egegik via a generator log Excel spreadsheet documenting several years of operation, including before the new powerplant was constructed, and current through late February 2017. The log isn't a true operational log, however, of hand or automated information per a certain time step; rather it's a daily summary of energy generated, generator runtime, fuel usage, etc. The log includes daily listing of average and maximum load in kW, but it's not clear how these data are derived as the spreadsheet does not include algorithms or equations for summery cells, just numbers. It appears that the generator log functions as an electronic logbook, not a true spreadsheet. Nevertheless, despite these issues, the data was useful for this report.

Considering only generator log spreadsheet data from the new powerplant, and started in January 2014, a gradual declining trend of average and maximum load demand through February 2017 is apparent per the graph below. Besides the declining load trend, most interesting is the large load peak in early and

[2] Due to low temperature operation at low engine loading, not all fuel is burned and passes "wet" into the exhaust system, or "stack", hence the term "wet stacking"; definition from Wikipedia.
[3] Efficiency data obtained from Gray Stassel Engineering, Inc. document, *16005 – Air Quality Compliance Report* for Alaska Energy Authority Rural Energy Group, November 2016

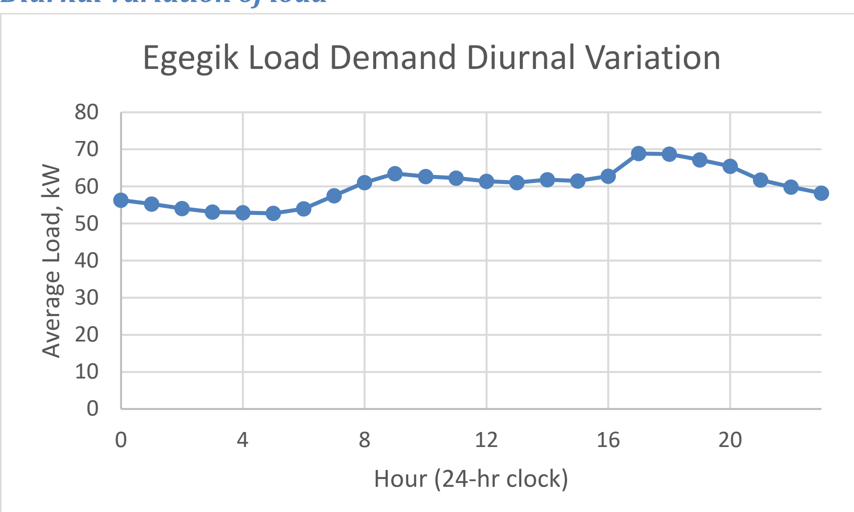
mid-summer when the Coffee Point Seafoods fish processing plant is operational. Summer load peak aside, one can see a typical seasonal variation of higher winter load demand, but in Egegik this is not nearly as prominant as seen in other rural Alaska communities.

Electric load trend



The Egegik powerplant is equipped with an automated logging system installed by AEA during construction. Three months of data – October 1 through December 29 – of 2014 data were obtained from AEA in 2015, but recent inquiries to AEA indicated that the system is off-line for unknown reasons and that data from it is no longer available. With use of AEA's December 2014 automated data, though, diurnal variation of load demand is documented per the following graph.

Diurnal variation of load



Combining the two data sources – the Egegik generator log spreadsheet (2016 data only) and AEA's 2014 automated powerplant log of diurnal variation – a table of monthly average load with diurnal variation was created. There is some loss of accuracy with this method in that the City of Egegik's generator log has daily data, but that data shows excessive day-to-day variation, which was thought unlikely and a probable artifact of the information gathering method. Averaging the monthly data though eliminates this suspicious variation and when combined with the diurnal variation per the AEA's 2014 powerplant data, the table below is derived.

Egegik monthly/hourly average load

Hour/Mo.	1	2	3	4	5	6	7	8	9	10	11	12
0	47	45	43	39	91	133	126	39	35	38	43	46
1	46	44	42	39	89	130	124	39	34	38	42	45
2	45	43	41	38	87	128	121	38	34	37	41	44
3	44	42	40	37	85	125	119	37	33	36	40	44
4	44	42	40	37	85	125	119	37	33	36	40	43
5	44	42	40	37	85	124	118	37	33	36	40	43
6	45	43	41	38	87	127	121	38	34	37	41	44
7	48	46	44	40	93	136	129	40	36	39	44	47
8	51	48	46	43	98	144	137	43	38	41	46	50
9	53	50	48	44	102	150	142	44	40	43	48	52
10	53	50	48	44	101	148	141	44	39	43	48	51
11	52	49	47	44	100	147	140	44	39	42	47	51
12	51	49	47	43	99	145	138	43	38	42	47	50
13	51	48	46	43	98	144	137	43	38	41	46	50
14	52	49	47	43	100	146	139	43	39	42	47	51
15	51	49	47	43	99	145	138	43	38	42	47	50
16	53	50	48	44	101	148	141	44	39	43	48	52
17	58	55	52	48	111	162	154	48	43	47	52	56
18	58	55	52	48	111	162	154	48	43	47	52	56
19	56	53	51	47	108	158	151	47	42	46	51	55
20	55	52	50	46	105	154	147	46	41	44	50	54
21	52	49	47	43	99	146	138	43	39	42	47	51
22	50	47	45	42	96	141	134	42	37	41	45	49
23	49	46	44	41	94	137	131	41	36	40	44	48

Thermal Load

The power plant is equipped with a district heat (recovered heat) system that serves the nearby Egegik Public School and Fisherman's Hall, the latter which also serves as a community center. The value of heat for the school, however, is diminished by the fact that Lake and Peninsula School District closed the school at the beginning of the 2015/16 school year due to a lack of registered students. The school was placed in mothball status with minimal heat, but apparently, the School District permanently closed the Egegik's school prior in 2016 by discontinuing heating the building. For both buildings, the thermal energy draw from the district heat loop is (or was) not documented, but since construction of the district heat loop with construction of the new power plant in 2013, Fisherman's Hall has not required supplemental heat from its fuel oil boiler. [4]

Wind-Diesel Hybrid Systems

Wind-diesel power systems are categorized based on their average penetration levels, or the overall proportion of wind-generated electricity compared to the total amount of electrical energy generated.

[4] School status and Fisherman's Hall information obtained from Don Strand, City of Egegik Administrator

Commonly used categories of wind-diesel penetration levels are very low, low, medium, and high penetration. The wind penetration level is roughly equivalent to the amount of diesel fuel displaced by wind power. Note however that the higher the level of wind penetration, the greater the complexity and expensive of the control system and demand-management strategy.

Categories of wind-diesel penetration levels

Penetration Category	Wind Penetration Level		Operating Characteristics and System Requirements
	Instantaneous	Average	
Very Low	<60%	<8%	• Diesel generator(s) runs full time • Wind power reduces net load on diesel • All wind energy serves primary load • No supervisory control system
Low	60 to 120%	8 to 20%	• Diesel generator(s) runs full time • At high wind power levels, secondary loads are dispatched to insure sufficient diesel loading, or wind generation is curtailed • Relatively simple control system
Medium	120 to 300%	20 to 50%	• Diesel generator(s) runs full time • At medium to high wind power levels, secondary loads are dispatched to insure sufficient diesel loading • At high wind power levels, complex secondary load control system is needed to ensure heat loads do not become saturated • Sophisticated control system
High (Diesels-off Capable)	300+%	50 to 150%	• At high wind power levels, diesel generator(s) may be shut down for diesels-off capability • Auxiliary components required to regulate voltage and frequency • Sophisticated control system

Note that medium penetration is a compromise between fuel use offset and relatively minimal system complexity and is the system configuration in most Alaska village wind-diesel systems, but given Egegik's low load demand and large capacity diesel generators, medium penetration advantages would more likely be liabilities. For the City of Egegik to pursue wind power, it would need to consider an all-or-nothing approach: either very low or low penetration, or high penetration.

Proposed Wind Turbines

Wind turbine options for Egegik range from farm to village scale size, or about 10 to 100 kW capacity. Note that this compares to utility-scale wind turbines which are 1,000 kW and larger. There are several new turbines available on the market that could be considered, two small farm-scale models and two larger villages-scale models.

Note that used and remanufactured turbines in the 10 to 100 kW capacity range are available from various sources and possible options, but due to unpredictable market availability are not evaluated in this report.

Farm-Scale Wind Turbines

The smaller farm-scale wind turbines considered in this feasibility study are the American-manufactured Bergey Excel 10 and the Canadian-manufactured Eocycle EO25. The advantage of these, and similar, wind turbines is that they are relatively easy to install and their capacity rating better suited to Egegik's low winter, spring and autumn electric load demand.

Bergey Excel 10

Thirty years ago, Bergey pioneered the radically simple "three moving parts design" that has proven to provide the best reliability, service life, and value of all the hundreds of competitive designs that have come and gone in that time. A small wind turbine is a big investment and Bergey is clearly the wise choice.[5]

Specifications:

- Reference rated power: 10 kW
- 3-blade, fixed pitch, upwind, horizontal axis
- Direct-drive (no gearbox), permanent magnet, 3-phase 240 VAC generator
- Auto-furl overspeed protection
- AWEA[6] rated power: 8.9 kW at 11 m/s (24.6 mph)
- AWEA rated annual energy: 13,800 kWh at 5 m/s (11 mph) average wind speed
- AWEA rated sound level: 42.9 dBA cut-in wind speed: 2.5 m/s (5.6 mph)
- Maximum design wind speed: 60 m/s (134 mph)
- Turbine Rotor Diameter: 7 m (23 ft.)

Tower options include guyed lattice, tilt-up guyed tubular, self-supporting lattice, tilt-up guyed lattice, and monopole. Available hub heights are 18 to 49 meters. Bergey towers use American-made steel and are assembled in the United States. A Bergey Excel 10 specification sheet is included in Appendix B of this report.

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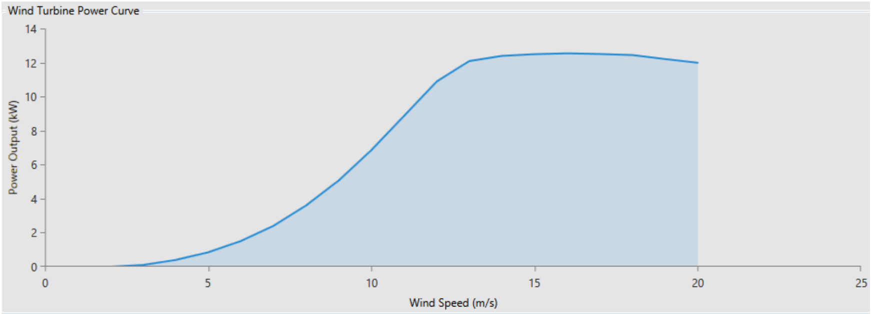
[5] Bergey product brochure information

[6] American Wind Energy Association

Bergey Excel 10 power curve[7]



Eocycle EO25 Class IIA

The Eocycle EO25 evaluated in this report is an IEC Class IIA variant. It's a direct-drive wind turbine manufactured in Canada that represents the next-generation wind turbine for the distributed wind energy (DWE) industry per company literature, bringing the most recent technology advancements of utility-scale wind within reach of small wind customers.

The EO25 has been designed and tested per the most stringent standards and to be the safest and most durable small wind turbine available on the market. Its robust construction allows it to be installed in higher wind regimes and to withstand gusts of up to 59.5 m/s (133 mph). Safety and durability characteristics of the EO25 include:

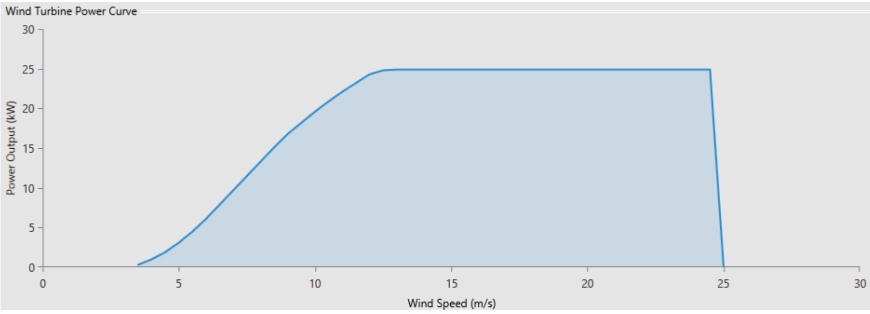
- Rated power: 25 kW; rotor diameter: 12.6 m
- Redundant rotor overspeed protection and fail-safe emergency disc brake
- Integrated protection against lightning
- 20-year design life in accordance with the IEC 61400-2, Wind Class II standard
- Marine-grade corrosion protection on all components
- Independently-tested carbon and glass fiber/epoxy resin composite blades that will last and procure stable performance under repetitive cyclic loading
- Standard safety devices on nacelle, tower climbing system and work platform and all electrical cabinets
- Design and construction like advanced utility-scale wind turbines
- Certification to AWEA and BWEA standards (in progress, testing to be completed in November 2013)
- Conforms with all applicable European Community directives (CE marking)
- Power inverter certified to UL and CSA standards
- Best-in-class components exclusively manufactured in North America and Europe

Tower options are self-supporting 16 m and 23 m hydraulic and 30 m and 36 m non-hydraulic. Eocycle notes that all towers are hot-dip galvanized and supplied with work platform, climbing step bolts ad

[7] From HOMER software component turbine library, which references a Small Wind Certification Council (SWCC) Summary Report, October 2012

safety cable. Standard warranty is two years; extended warranty is five years. The turbine can be equipped for arctic temperatures. An Eocyle EO25 specification sheet is included in Appendix C of this report.

Eocycle EO25 power curve[8]



Village-Scale Wind Turbines

The village-scale wind turbines considered in this feasibility study are the American-manufactured Northern Power Systems NPS100 and the Belgian-manufactured XANT M-24. The NPS100 is the most widely installed wind turbine in Alaska and is the default choice for many village wind power projects. The XANT is new to the market and offers some construction advantages over the NPS100.

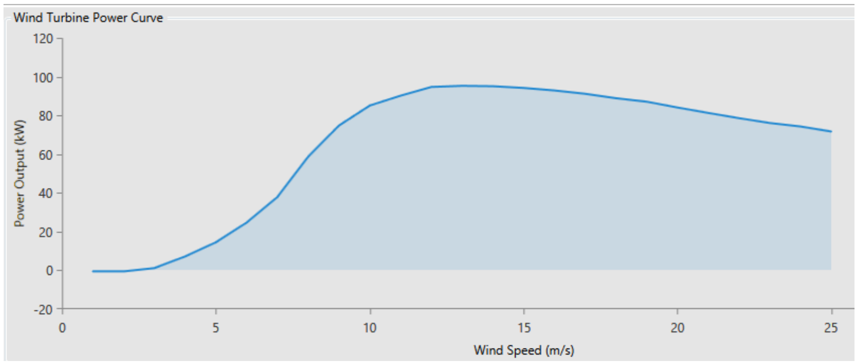
Northern Power Systems NPS100

The Northern Power Systems NPS 100C-24 is rated at 95 kW and is equipped with a permanent magnet, synchronous generator for direct drive (no gearbox) operation. The turbine has a 24.4-meter diameter rotor and is available with three tubular tower heights: 22, 29, and 37 meters. The NPS 100C-24 is specifically optimized for lower wind speed sites and is marketed as a IEC 61400-1, 3rd edition, Class III-C turbine. The NPS100 is also available with a 21 meter rotor for IEC Class IA winds, but the 24 meter rotor version is more suitable for the Egegik wind regime.

The NPS 100C-24 is stall-regulated and for Egegik possibly would be equipped with an arctic package enabling operation at temperatures as low as -40° C. The NPS 100 is the most widely represented village-scale wind turbine in Alaska with a significant number of installations in the Yukon-Kuskokwim Delta and on St. Lawrence Island. The NPS 100 wind turbine is manufactured in Barre, Vermont, USA. More information can be found at http://www.northernpower.com/. A Northern Power Systems NPS100-24 specification sheet is included in Appendix D of this report.

[8] From HOMER software component turbine library, which states that the power curve was obtained from the manufacturer.

NPS 100C-24 power curve[9]



XANT M-24

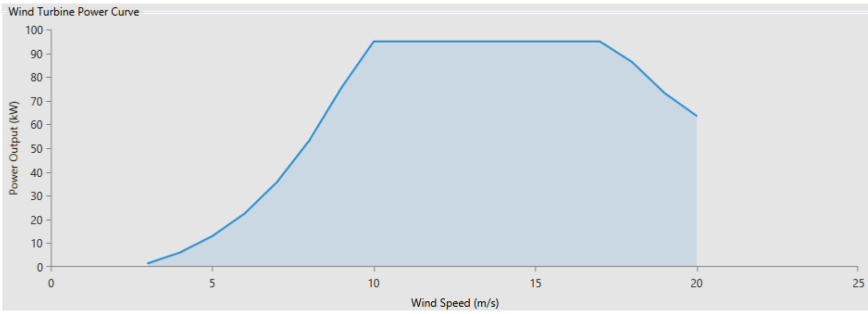
The XANT M-24 is a direct drive (no gearbox), downwind, variable-speed, stall-controlled wind turbine equipped with a permanent magnet, synchronous, 95 kW generator. Power output is controlled via a 4-quad converter located, with all other power electronics for the turbine, at the base of the tower. The turbine is design class IEC WTGS IIIA and is equipped with a 24-meter diameter three-blade rotor. Power electronics equipment for the turbine is housed in the turbine nacelle and the base of the tower. The XANT M turbine is also available with a 21 meter rotor for IEC Class IA winds, but the M-24 is more suitable for Egegik.

Tower options include free-standing tubular monopole and guy wire-stabilized, tilt-up tubular monopole, both external climb. The most appropriate option for Egegik may be the 32 meter guyed, tilt-up tower.

The XANT M-24 can be equipped with black color, hydrophobic material-coated rotor blades and a cold weather package enabling continuous operation at temperatures to -40° C. The XANT M-24 is new to the Alaska market with an installation in the Yukon-Kuskokwim Delta region planned in 2017. The turbine is manufactured in Brussels, Belgium. More information can be found at http://xant.be/en/. Power and thrust coefficient curves of the XANT M-24 are shown below. A XANT M-24 specification sheet is included in Appendix E of this report.

[9] From HOMER software component library. Matches specification information from Northern Power Systems.

XANT M-24 power curve[10]



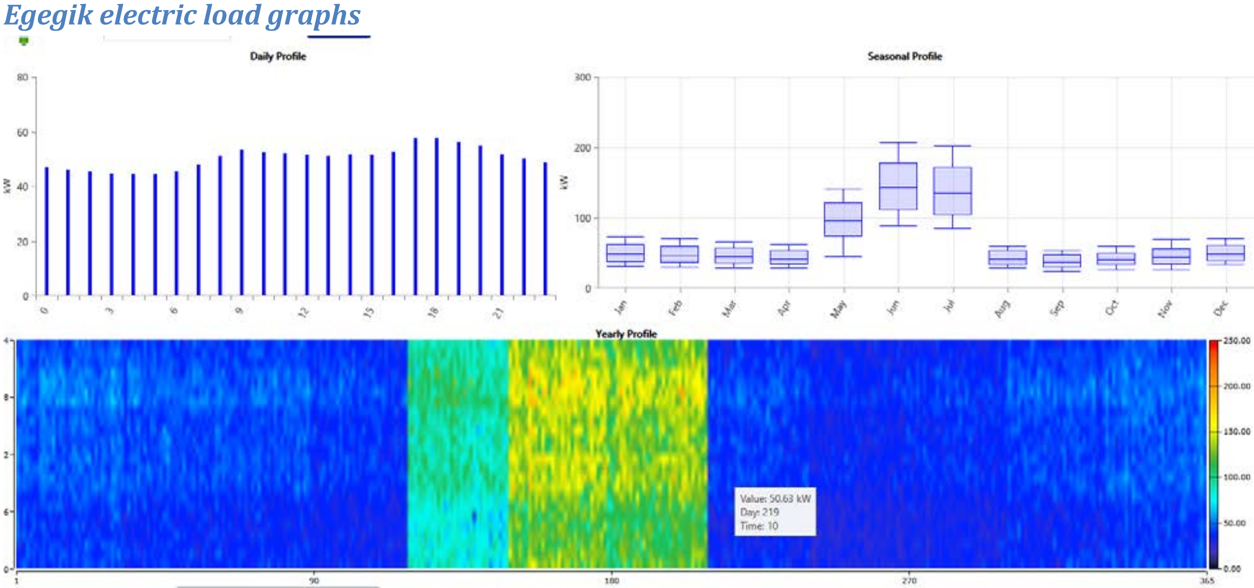
HOMER Modeling

HOMER energy modeling software was used to analyze the Egegik power system. HOMER is a static energy balance and financial model designed to optimize hybrid power system designs that contain a mix of conventional and renewable energy sources, such as diesel generators, wind turbines, solar panels, batteries, etc. HOMER software is widely used in Alaska to aid development of village wind-diesel power projects. For Egegik, the model was prepared using one-hour time steps, resulting in 8,760 separate time step analyses for one year.

Electric Load Demand

The table of monthly average data with diurnal variation was uploaded to the Egegik HOMER model and randomization was introduced with 5% day-to-day and 10% timestep-to-timestep variability. This yields a more typical load curve than no randomization, but the methodology to create the load profile likely overestimated load demand in early May and again in late July (before and after the peak season of fish processing). Following are HOMER software-generated graphics of the processed Egegik electric load.

Egegik electric load graphs



[10] From HOMER software component library. Matches power curve in XANT M-24 General Specifications obtained from manufacturer.

Thermal Load Demand

The only thermal load at present on the district (recovered) heat loop is Fisherman's Hall, which also functions as the community center. The Egegik Public School had been served by this heat loop, but it is shut down and no longer being heated. This school status could change in the future, but the likelihood of that possibility is uncertain.

For the HOMER model, the thermal load is not modeled due to insufficient information, but with only one minimal heat load (Fisherman's Hall), it is not significant. Possibly with sufficient wind turbine capacity the heat output of the diesel engine(s) would be reduced enough to force the auxiliary fuel oil boiler in Fisherman's Hall to operate to provide heat, but this would only be likely on very cold winter days when wind turbine input is high and electrical load demand relatively low.

Modeling Assumptions

HOMER modeling assumptions are detailed in the table below. Many assumptions, such as project life, discount rate, operations and maintenance (O&M) costs, etc. are AEA default values. The base or comparison scenario is the existing Egegik power plant with its present configuration of four diesel generators.

HOMER modeling assumptions

Operating Reserves		
	Load in current time step	10%
	Wind power output	50% (to cover loss of one wind turbine if two are operational)
Diesel Generators		
	Minimum load	20%
	Schedule	Optimized; always diesels-on
Environmental		
	Wind speed	7.43 m/s (16.6 mph) at 34 m (112 ft.) AGL, met tower site
	Wind shear	0.216 power law exponent
	Temperature	2.1° C (35.8° F) mean annual
Wind Turbines		
	Net AEP	85% (net all losses: icing, wake, O&M, electrical, soiling, etc.)
Energy Loads		
	Electric	1.55 MWh/day average Egegik electric load
	Thermal	District heat loop

HOMER Model Results

HOMER energy modeling software was used to calculate wind turbine energy production and excess energy available (not demanded by the electrical load). Note that inclusion of wind turbines as a wind-diesel power system, even at lower penetration levels, can result in energy generation greater than electrical load demand. This is due to spinning reserve and minimum loading requirements of the diesel generators. Note that wind turbine energy production in these analyses is calculated at 85 percent of gross. HOMER software does not model system dynamic response and hence possible system instability and control counter-measures must be addressed during design.

Wind-Diesel, Farm-Scale Wind Turbines

Installation of farm-scale wind turbines offers Egegik the potential to benefit from wind power without an "all-in" commitment such as would be necessary with village-scale wind turbines. The wind turbines would operate in parallel with the diesel generators. If sufficient excess energy is anticipated, a secondary load controller and electric boiler could be employed in the district heat loop to serve thermal loads at Fisherman's Hall, although this would be very expensive and of minimal benefit with the school no longer open, or even heated.

Battery and converter (inverter/rectifier) systems to store energy can mitigate the problem of excessive wind power production and low diesel loading, but are expensive and would not be cost effective with installation of only one or two farm-scale wind turbines.

Bergey Excel 10 Turbine

This configuration is *two* Bergey Excel wind turbines on 30 meter tower tilt-up towers at the met tower site. In this scenario, wind turbine energy production (percent electrical energy produced from wind) would be 8.6%. But, despite this low wind energy production percentage, excess energy is modeled at 5.9% of energy generated, indicating that much of the generated wind energy (35.7 MWh/year of 51.9 MWh/yr; note that excess electricity also includes diesel generation) would be wasted via curtailment of one or both wind turbines, or via a load bank to dissipate excess energy as heat to the atmosphere. The resulting renewable energy fraction (energy delivered to the load that originated from wind power) would be only 2.9%.

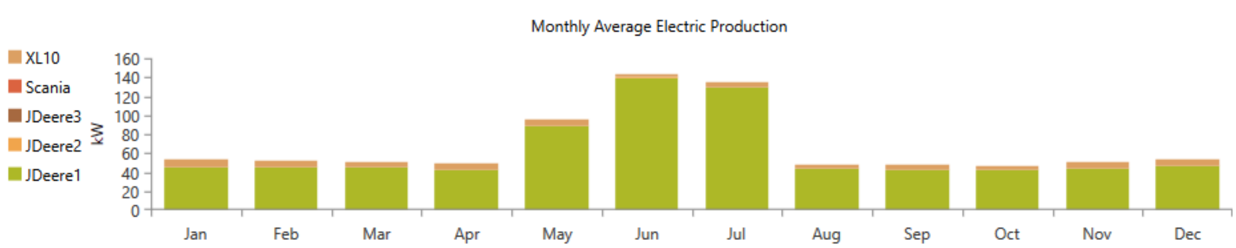
Energy table, met tower site, two Bergey turbines, 85% net AEP

Production	kWh/yr	%
JD6090Tier2marine	550,302	91.32
JD6090Tier2marine (1)	336	0.06
Scania400marine	0	0.00
JD6090Tier2marine (2)	0	0.00
Bergey Excel 10	51,939	8.62
Total	602,577	100.00

Consumption	kWh/yr	%
AC Primary Load	566,845	100.00
DC Primary Load	0	0.00
Total	566,845	100.00

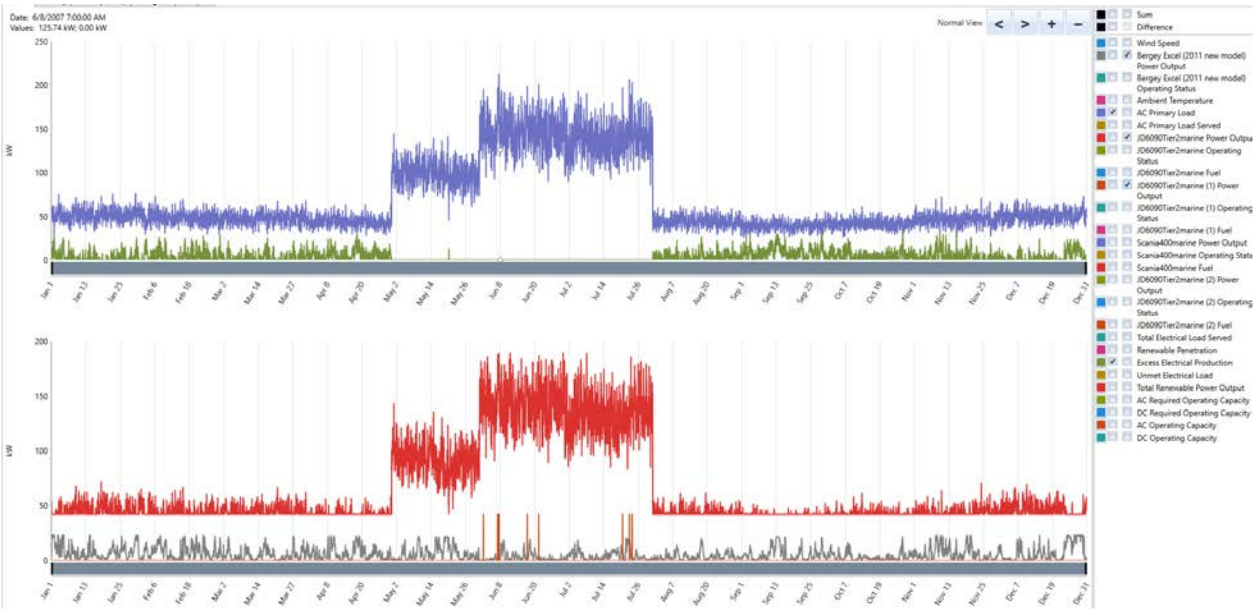
Quantity	kWh/yr	%
Excess Electricity	35,732.1	5.9
Unmet Electric Load	0.0	0.0
Capacity Shortage	0.0	0.0

Quantity	Value
Renewable Fraction	2.9
Max. Renew. Penetration	71.7



The following combined chart is perhaps somewhat difficult to interpret, but it demonstrates the challenge with wind power in Egegik, even with a low 20 kW wind power capacity with two Bergey 10 wind turbines. The top graph shows electric load demand and excess energy production, while the bottom graph shows diesel engine and wind turbine power production. During the summer fish processing season, electric load demand is high enough to absorb all wind energy production, but during the longer off-season months, electric load demand is so low that even with the single operating diesel engine at its minimum 20% loading, there's not enough load demand to absorb most of the even minimal wind energy produced.

Power charts: top, load demand (purple) and excess power (green); bottom, diesel loading (red) and Bergey turbine power (grey)



Eocycle EO25 Turbine

This configuration is one Eocycle EO25 wind turbine on a 23 meter hydraulically-lifted, self-supporting tower at the met tower site. In this scenario, wind turbine energy production (percent electrical energy produced from wind) would be 11.3%. But, similarly to the scenario of two Bergey wind turbines, excess energy is modeled at 7.5% of energy generated, indicating that much of the generated wind energy (46.2 MWh/year of 69.4 MWh/yr; note that excess electricity also includes diesel generation) would be wasted via curtailment of one or both wind turbines, or via a load bank to dissipate excess energy as heat to the atmosphere. The resulting renewable energy fraction (energy delivered to the load that originated from wind power) is only 4.1%, which mirrors the Bergey turbine scenario result.

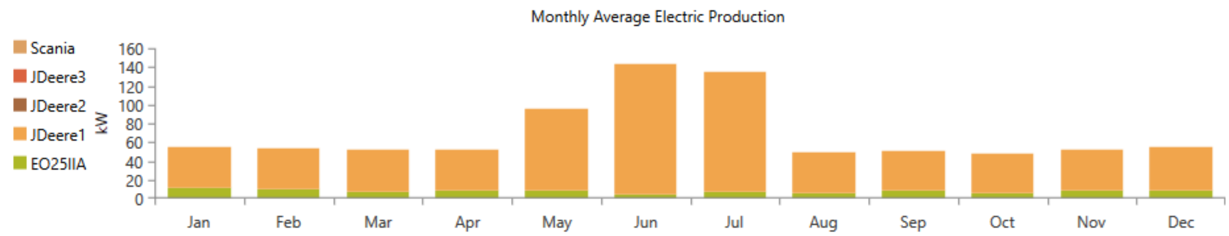
Energy table, met tower site, one EO25 turbine, 85% net AEP

Production	kWh/yr	%
JD6090Tier2marine	543,275	88.62
JD6090Tier2marine (1)	336	0.05
Scania400marine	0	0.00
JD6090Tier2marine (2)	0	0.00
Eocycle EO25 Class IIA	69,424	11.32
Total	613,035	100.00

Consumption	kWh/yr	%
AC Primary Load	566,845	100.00
DC Primary Load	0	0.00
Total	566,845	100.00

Quantity	kWh/yr	%
Excess Electricity	46,190.0	7.5
Unmet Electric Load	0.0	0.0
Capacity Shortage	0.0	0.0

Quantity	Value
Renewable Fraction	4.1
Max. Renew. Penetration	73.4



Wind-Diesel, Village-Scale Wind Turbines

Installation of one or more approximately 100 kW capacity village-scale wind turbines in Egegik would truly be an "all-in" commitment for the community. The wind turbines would operate in parallel with the diesel generators. If sufficient excess energy is anticipated, a secondary load controller and electric boiler could be employed in the district heat loop to serve thermal loads at Fisherman's Hall, although this would be very expensive and of minimal benefit with the school no longer open, or even heated.

While battery and converter (inverter/rectifier) systems to store energy can mitigate the problem of excessive wind power production and low diesel loading, they are expensive and complex, but almost certainly necessary for a successful project employing higher-capacity village-scale turbines.

NPS100-24 Turbine

This configuration is one Northern Power Systems NPS100-24 wind turbine on a 30 meter tower at the met tower site. In this scenario, wind turbine energy production (percent electrical energy produced from wind) would be 40.2%. But, excess energy would be an extraordinarily high 29.7% of energy generated with 74% of the generated wind energy not serving the electric load. The resulting renewable energy fraction (energy delivered to the load that originated from wind power) would be a very low 14.9% considering the very high 40.2% wind turbine production.

Note that 100 kW of wind power capacity without storage is not a viable wind-diesel system configuration for Egegik, but is presented here to illustrate the situation of very low load demand coupled with large diesel generators. The result is grossly insufficient margin for wind turbines to contribute their energy production to offset the electric load. The margin issue is significant even with only 20 kW of wind turbine capacity, but would be completely unmanageable with 100 kW of wind capacity.

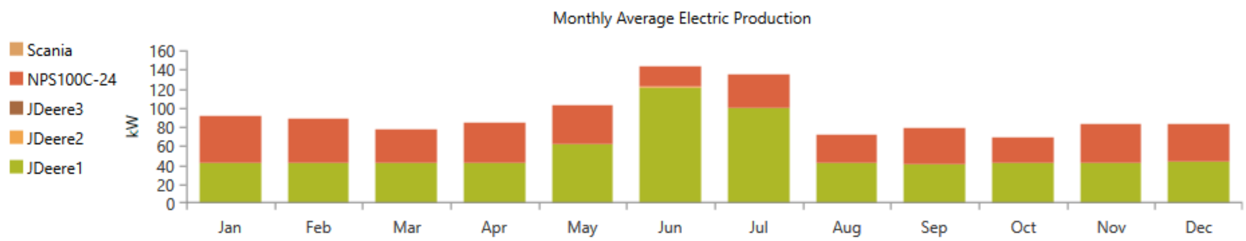
Energy table, met tower site, one NPS100-24 turbine, 85% net AEP

Production	kWh/yr	%
JD6090Tier2marine	482,421	59.81
JD6090Tier2marine (1)	168	0.02
Scania400marine	0	0.00
JD6090Tier2marine (2)	0	0.00
Northern Power NPS100C-24	323,969	40.17
Total	806,558	100.00

Consumption	kWh/yr	%
AC Primary Load	567,064	100.00
DC Primary Load	0	0.00
Total	567,064	100.00

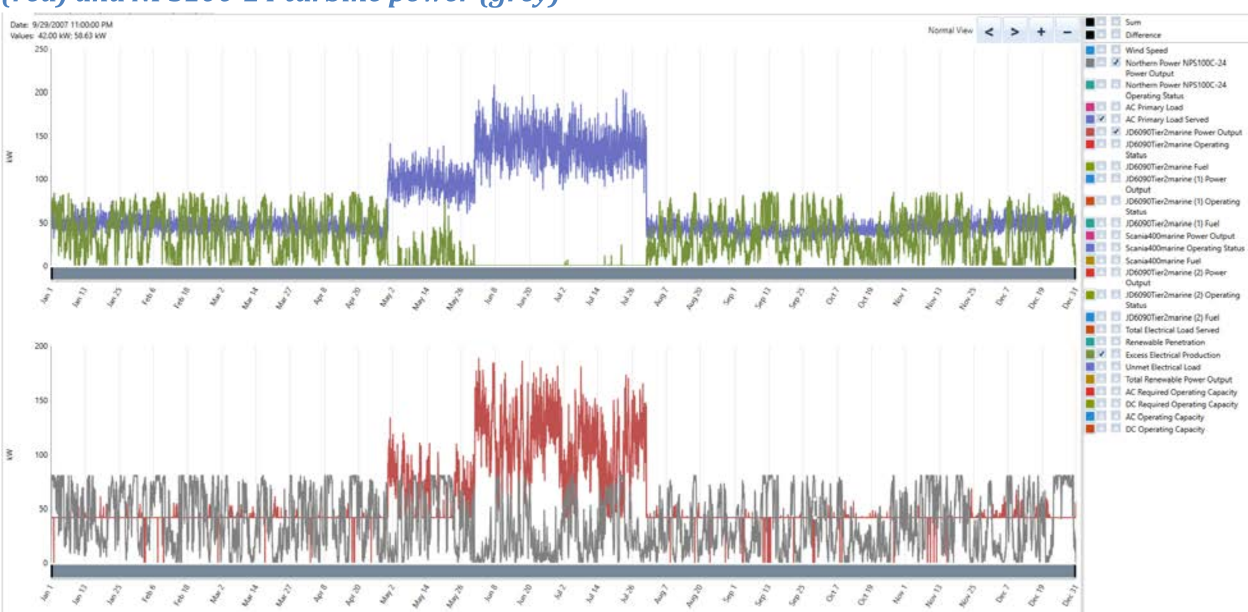
Quantity	kWh/yr	%
Excess Electricity	239,494.3	29.7
Unmet Electric Load	0.0	0.0
Capacity Shortage	0.0	0.0

Quantity	Value
Renewable Fraction	14.9
Max. Renew. Penetration	308.5



The following chart, as was presented for the scenarios of Bergey and Eocyle wind turbines, demonstrates the now untenable problem of excess wind energy production (green line in top graphic) in all months but June and July.

Power charts: top, load demand (purple) and excess power (green); bottom, diesel loading (red) and NPS100-24 turbine power (grey)



XANT M-24 Turbine

This configuration is one XANT M-24 wind turbine on a 23 meter guyed, tilt-up tower at the met tower site. In this scenario, wind turbine energy production (percent electrical energy produced from wind) would be 40.4%. But, like with the NPS100-24 single turbine configuration, excess energy would be a very high 29.8% of energy generated with 74% of the generated wind energy not serving the electric load. The resulting renewable energy fraction (energy delivered to the load that originated from wind power) would be a low 15.2%.

As with the NPS100-24 configuration, one XANT M-24 operated in parallel with the diesel generators is not a viable wind-diesel system configuration for Egegik, but is presented here to demonstrate the energy production potential of the XANT wind turbine, which could be employed in a configuration that includes battery storage.

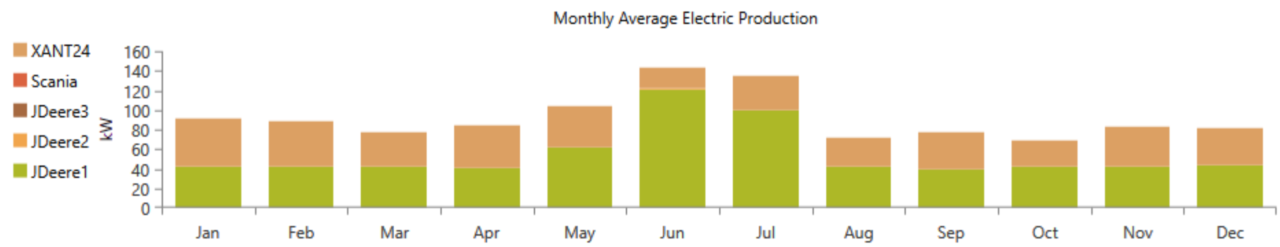
Energy table, met tower site, one XANT M-24 turbine, 85% net AEP

Production	kWh/yr	%
JD6090Tier2marine	480,724	59.53
JD6090Tier2marine (1)	210	0.03
Scania400marine	0	0.00
JD6090Tier2marine (2)	0	0.00
XANT M-24 [95kW]	326,541	40.44
Total	807,475	100.00

Consumption	kWh/yr	%
AC Primary Load	567,064	100.00
DC Primary Load	0	0.00
Total	567,064	100.00

Quantity	kWh/yr	%
Excess Electricity	240,411.1	29.8
Unmet Electric Load	0.0	0.0
Capacity Shortage	0.0	0.0

Quantity	Value
Renewable Fraction	15.2
Max. Renew. Penetration	314.6



Summary of Wind Power Options with Existing Powerplant

Note again that the wind power configurations presented in this section presume parallel operation of the wind turbine(s) and diesel generators with no energy storage. Equipment, such as a secondary load controller combined with an electric boiler in the district heat loop, or a resistive simple load bank to atmosphere, to absorb excess energy production has not been explicitly modeled, but excess energy transfer through such a device is implied. If no secondary load controller were installed, then turbine dispatch controller to curtail (shut down) the wind turbine when the margin between load demand and minimum diesel load (42 kW for the John Deere 6090 generators) is insufficient to accept the available wind power input. The latter though has been proven as a particularly inefficient and problematic control methodology and should be avoided.

The following summary table well illustrates the challenge in Egegik of introducing wind power to the existing powerplant. There's simply insufficient margin between the diesel generator minimum loading and the load demand to accommodate wind power, and hence even low capacity wind turbine configurations, such as two 10 kW Bergey 10 turbines, produce a considerable amount of excess energy and are only marginally effective with respect to renewable fraction.

Summary table of wind power options, existing powerplant

Configuration	No. Turbs.	Turbine Capacity (kW)	Diesel Energy (kWh)	Wind Energy (kWh)	Total Product. (kWh)	Wind Energy Ratio (%)	Electric Load (kWh)	Excess Energy (kWh)	Excess Energy (%)	Renew. Fraction (%)
Bergey 10	2	20	550,638	51,939	602,577	8.6%	566,845	35,732	5.9%	2.9%
Eocycle EO25	1	25	543,611	69,424	613,035	11.3%	566,845	46,190	7.5%	4.1%
NPS100-24	1	95	482,589	323,969	806,558	40.2%	566,845	239,713	29.7%	14.9%
XANT M-24	1	95	480,934	326,541	807,475	40.4%	566,845	240,630	29.8%	15.2%

Alternative Diesel Generator Option

An option to significantly improve the usability of wind turbines in Egegik would be to replace one of the three 210 kW John Deere 6090 diesel generators in the powerplant with a smaller model of approximately 100 kW capacity. Although a 100 kW capacity diesel generator is not necessarily more efficient than the existing JD 6090 generators, with the addition of wind turbines a smaller unit increases the margin between the load demand and minimum diesel loading. This enables more usability of wind energy.

Diesel generator options in the 100 kW capacity range, however, are limited. Alaska Energy Authority[11] suggests a John Deere 4045AFM85 engine with a 101 kW generator as an option, but noted that market availability of the more desirable (for rural Alaska) model year 2013 Tier 3 unit may be challenging.[12]

Note that a JD 4045 is a less efficient engine than the JD 6090, with an energy generation efficiency at 75% load of 12.9 kWh/gal versus 13.5 kWh/gal for the JD 6090. But, in Egegik the JD 6090 engines rarely operate at 75% load. More typically they operate at about 25% loading (52 kW), where their fuel efficiency drops to 12.2 kWh/gal. Interestingly, this is slightly better than the 11.7 kWh/gal energy generation efficiency of the JD4045 at 50% loading (50 kW), but again, the primary issue for Egegik with wind-diesel is the margin between electrical load demand and minimum diesel loading, not the intrinsic efficiencies of the generators themselves.

Proposed alternate Egegik diesel powerplant configuration with JD 4045 engine

Bay	Diesel Engine	Electrical Rating	Fuel effic. at 75% load[13]
1	John Deere 4045AFM85 Tier 3	101 kW	12.9 kWh/gal
2	John Deere 6090AFM75 (marine)	210 kW	13.5 kWh/gal
3	Scania DI13 075M (marine)	400 kW	15.3 kWh/gal
4	John Deere 6090AFM75 (marine)	210 kW	13.5 kWh/gal

Two configuration options – one Eocycle 25 and one XANT M-24 are presented in detail below, but a summary report of additional configuration options is presented at the end of this section.

[11] Discussions with David Lockard of Alaska Energy Authority.

[12] Model year 2014 and later John Deere 4045 engines are EPA Tier 4, which include a managed emissions package that would be difficult and expensive to maintain in Egegik.

[13] Efficiency data obtained from Gray Stassel Engineering, Inc. document, *16005 – Air Quality Compliance Report* for Alaska Energy Authority Rural Energy Group, November, 2016

Eocycle EO25 Turbine, JD 4045 Diesel

This configuration repeats the configuration one Eocycle EO25 wind turbine on a 23 meter hydraulic tilt-up tower at the met tower site, as evaluated previously, but with a 101 kW capacity JD 4045 diesel generator operating to a 20% minimum loading of 20 kW (versus a 42 kW minimum with a 210 kW generator). In this scenario, wind turbine energy production (percent electrical energy produced from wind) would be 10.0%. But, because there would be sufficient margin between electric load demand and minimum diesel generator loading, excess energy is modeled at only 0.1% of energy generated, indicating very little of the wind energy would be wasted. The resulting renewable energy fraction (energy delivered to the load that originated from wind power) rises to 10.0%, versus only 3.2% in the previous evaluation using the existing 210 kW diesel generators.

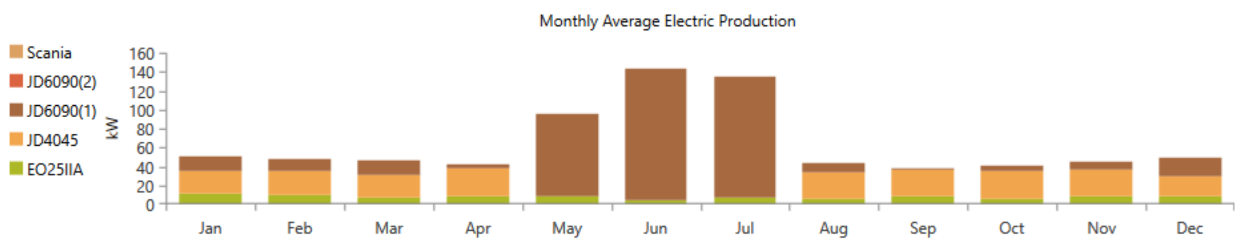
Energy table, one EO25 turbine, one John Deere 4045 diesel, 85% net AEP

Production	kWh/yr	%
JD6090Tier2marine	325,227	57.31
JD6090Tier2marine (1)	0	0.00
Scania400marine	0	0.00
JD4045AFM85	172,825	30.46
Eocycle EO25 Class IIA	69,424	12.23
Total	567,476	100.00

Consumption	kWh/yr	%
AC Primary Load	566,845	100.00
DC Primary Load	0	0.00
Total	566,845	100.00

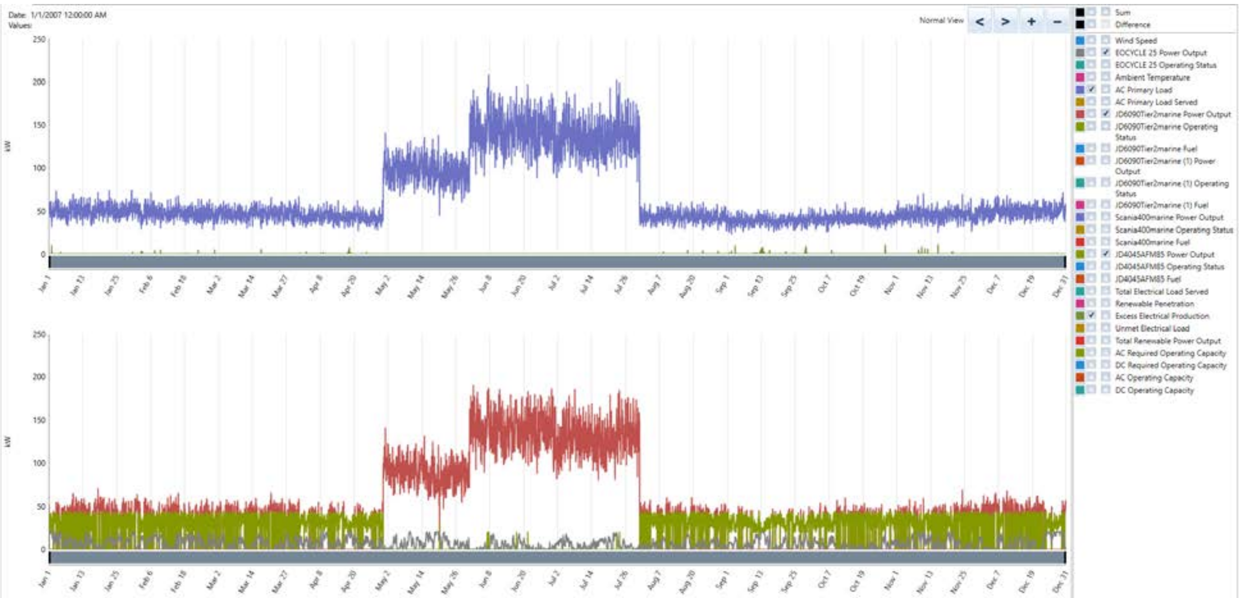
Quantity	kWh/yr	%
Excess Electricity	630.8	0.1
Unmet Electric Load	0.0	0.0
Capacity Shortage	0.0	0.0

Quantity	Value
Renewable Fraction	12.1
Max. Renew. Penetration	73.4



The following chart demonstrates that by replacing one of the 210 kW John Deere 6090 diesel generators with a smaller 101 kW John Deere 4045 unit, there is little excess energy from one Eocycle EO25 wind turbine. In the lower graph, however, the model suggests that to provide sufficient spinning reserve in event of a wind turbine fault, a JD6090 would often need to operate in parallel with the JD4045, negating some of the effectiveness of this arrangement. In this case, possibly it would be preferable to install two JD 4045 units, or modify spinning reserve requirements to be less conservative, although the latter may increase the risk of system black-out with a sudden drop in wind speed or from a turbine fault which immediately takes it off-line.

Power charts: top, load demand (purple) and excess power (green); bottom, diesel loading (red and light green) and Eocycle turbine power (grey)



Eocycle EO25 Turbine, 2 Turbines, JD 4045 Diesel

This configuration evaluates two Eocycle EO25 wind turbines on 23 meter hydraulic tilt-up towers at the met tower site with a 101 kW capacity JD 4045 diesel generator operating to a 20% minimum loading of 20 kW to replace one of the 210 kW JD 6090 generators. In this scenario, wind turbine energy production (percent electrical energy produced from wind) would be 23.8%. But, because there would be sufficient margin between electric load demand and minimum diesel generator loading, excess energy is modeled at only 3.0% of energy generated, indicating that only a minimal amount of wind energy production (17.6 MWh/yr of 138.8 MWh generated; note that excess electricity also includes diesel generation) would be wasted. The resulting renewable energy fraction (energy delivered to the load that originated from wind power) rises to 21.4%.

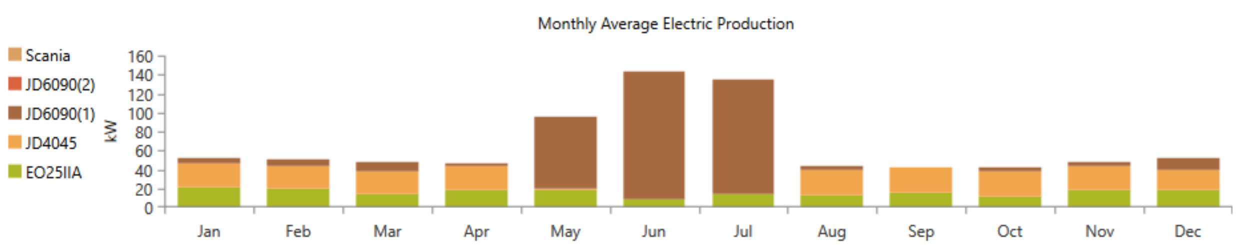
Energy table, two EO25 turbines, one John Deere 4045 diesel, 85% net AEP

Production	kWh/yr	%
JD6090Tier2marine	283,420	48.49
JD6090Tier2marine (1)	0	0.00
Scania400marine	0	0.00
JD4045AFM85	162,190	27.75
Eocycle EO25 Class IIA	138,847	23.76
Total	584,458	100.00

Consumption	kWh/yr	%
AC Primary Load	566,845	100.00
DC Primary Load	0	0.00
Total	566,845	100.00

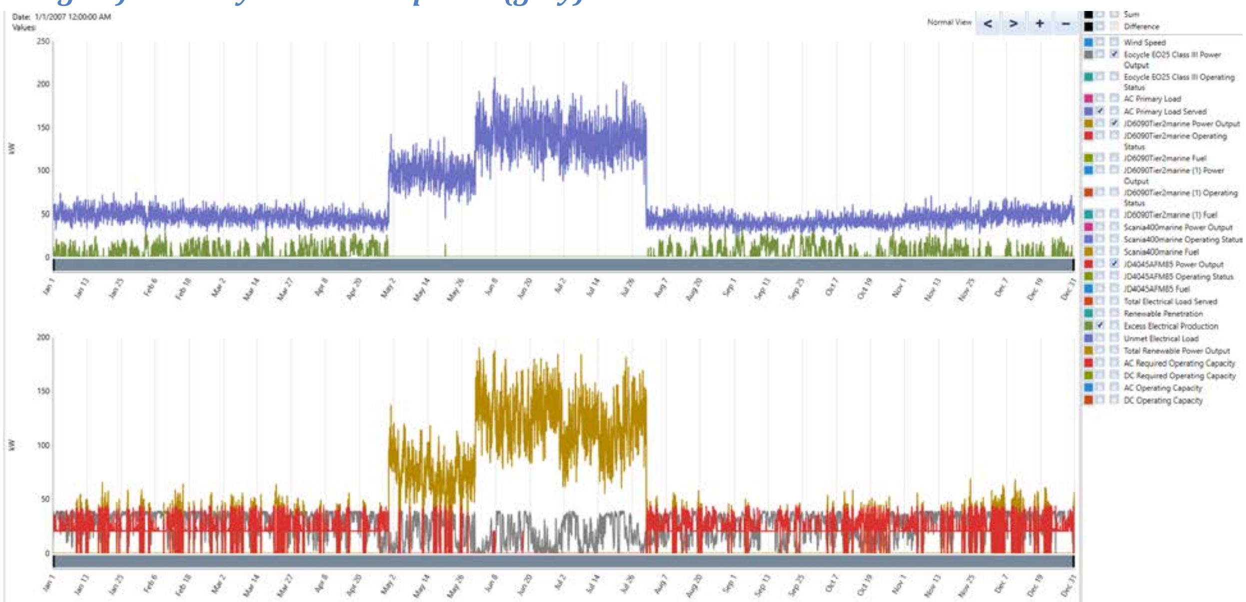
Quantity	kWh/yr	%
Excess Electricity	17,612.7	3.0
Unmet Electric Load	0.0	0.0
Capacity Shortage	0.0	0.0

Quantity	Value
Renewable Fraction	21.4
Max. Renew. Penetration	146.8



The following chart of load demand, diesel and Eocycle wind turbine output, and excess power demonstrates that approximately 50 kW of wind power capacity, combined with a 101 kW diesel generator strikes a balance between wind generation and system stability. Two turbines would enable dispatch control (taking one turbine off line) of the turbines when necessary to reduce wind power intput, and/or a secondary load controller attached to a load bank (to atmosphere) could be employed.

Power charts: top, load demand (purple) and excess power (green); bottom, diesel loading (red and gold) and Eocycle turbines power (grey)



One XANT M-24 Turbine, JD 4045 Diesel

This configuration is one XANT M-24 wind turbine on a 32 meter tilt-up tower at the met tower site, as evaluated previously, but with a 101 kW capacity JD 4045 diesel generator operating to a 20% minimum loading of 20 kW. In this scenario, wind turbine energy production (percent electrical energy produced from wind) would be a high 47.0%. Now with more margin between electric load demand and minimum diesel generator loading, excess energy is modeled at 18.4% of energy generated, versus 29.8% with the JD 6090 as the smallest diesel generator. The resulting renewable energy fraction (energy delivered to the load that originated from wind power) rises would be 35.1%, versus a very low 15.2% in the previous evaluation without the JD 4045.

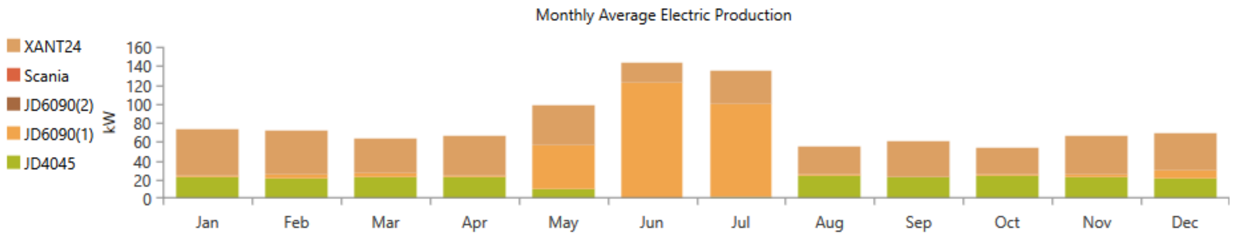
Energy table, one XANT M-24 turbine, one JD 4045 diesel, 85% net AEP

Production	kWh/yr	%
JD6090Tier2marine	211,949	30.52
JD6090Tier2marine (1)	0	0.00
Scania400marine	0	0.00
JD4045AFM85	156,056	22.47
XANT M-24 [95kW]	326,541	47.01
Total	694,546	100.00

Consumption	kWh/yr	%
AC Primary Load	566,845	100.00
DC Primary Load	0	0.00
Total	566,845	100.00

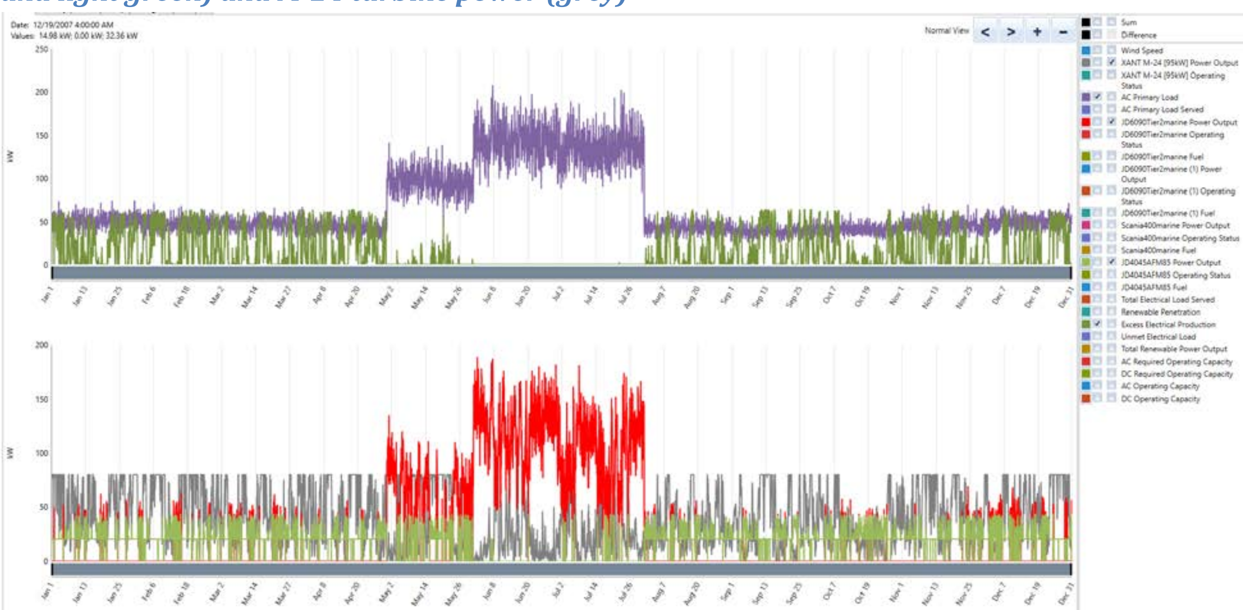
Quantity	kWh/yr	%
Excess Electricity	127,700.7	18.4
Unmet Electric Load	0.0	0.0
Capacity Shortage	0.0	0.0

Quantity	Value
Renewable Fraction	35.1
Max. Renew. Penetration	314.8



Note, however, that the 95 kW of wind capacity in this single XANT turbine configuration may be difficult to control, especially when the JD 4045 is operating at minimum loading. Besides a secondary load controller paired with an electric boiler or load bank to atmosphere, the XANT may require electronic throttling control (via its own load bank at the turbine) to match wind power output to the electric load demand minus minimum JD 4045 diesel loading margin. This control mechanism, however, increases system complexity. The following chart indicates the load, diesel, wind turbine, and excess energy dynamics.

Power charts: top, load demand (purple) and excess power (green); bottom, diesel loading (red and light green) and M-24 turbine power (grey)



Summary of Wind Power Options with 101 kW John Deere 4045 Diesel Generator

Replacing one or two of the existing John Deere 6090 diesel generators in the Egegik powerplant with a smaller capacity John Deere 4045 model creates an opportunity for the introduction of wind power that otherwise seems unlikely. As previously noted, this is due to the wider margin between 20 percent minimum diesel loading (20 kW for the JD 4045) and the often very low electric load demand during the non-fish processing months (August through mid-May).

The following table is a summary of wind power configurations discussed in this section; compare to the earlier table of wind power options summary within the existing powerplant.

Note that the configuration of two Eocycle EO25 wind turbines, for 50 kW of wind power capacity, appears to strike a balance between wind energy production and minimal excess energy. Besides the Eocycle turbine option, this capacity goal could also be achieved with use of five Bergey 10 wind turbines.

Summary table of wind power options, with 101 kW diesel generator

Configuration	No. Turbs.	Turbine Capacity (kW)	Diesel Energy (kWh)	Wind Energy (kWh)	Total Product. (kWh)	Wind Energy Ratio (%)	Electric Load (kWh)	Excess Energy (kWh)	Excess Energy (%)	Renew. Fraction (%)
Bergey 10	2	20	515,275	51,939	567,214	9.2%	566,845	369	0.1%	9.1%
Eocycle EO25	1	25	498,052	69,424	567,476	12.2%	566,845	631	0.1%	12.1%
Eocycle EO25	2	50	445,611	138,847	584,458	23.8%	566,846	17,612	3.0%	21.4%
NPS100-24	1	95	367,080	323,969	691,049	46.9%	566,845	124,204	18.0%	35.2%
XANT M-24	1	95	368,005	326,541	694,546	47.0%	566,845	127,701	18.4%	35.1%

Economic Analysis

AEA's 2015 *EvaluationModelREFR9Final (1)* Excel spreadsheet was used to evaluate the potential economic benefit of a wind power project in Egegik. Because the Alaska Energy Authority did not sponsor a solicitation for the Renewable Energy Fund in 2016, for which the evaluation model was created to support, the evaluation spreadsheet was not updated and the 2015 model is the most recent.

Project Capital Cost

Capital and installation costs of wind turbines to serve Egegik are estimated by AEA's default wind project cost estimate of $10,897/kW of installed wind capacity for projects sized 1 MW capacity and less (or serving 1,000 people and less)[14]. There is considerably variability in this estimate though and it may not be wholly reflective of the challenges of constructing a wind project in Egegik.

Besides the cost of the wind turbine(s), wind power project cost estimates include mobilization and demobilization of construction equipment, personnel, project management, civil works improvements such as access roads and pads, turbine foundation(s), erection of the wind turbine(s), electrical distribution connection, site transformers (to step up turbine voltage to line voltage), and installation of control and monitoring equipment.

[14] Assumptions worksheet of 2015 *EvaluationModelREFR9Final (1)* Excel spreadsheet

Wind projects costs for conceptual design reports[15] recently written or co-written by V3 Energy have indicated that AEA's $10,897/kW cost estimate is too low. Higher accuracy cost estimates have consistently been higher by a factor of 1.25 to 2.0. Based on this experience, AEA's $10,897/kW cost estimate is increased by 30% for this feasibility study.

Estimated Egegik wind power project cost; existing powerplant

Configuration	No. Turbs.	Turbine Capacity (kW)	Project Cost Estimate
Bergey 10	2	20	$ 283,322
Eocycle EO25	1	25	$ 354,153
NPS100-24	1	95	$ 1,345,780
XANT M-24	1	95	$ 1,345,780

Note, however, that a wind project does not typically also include diesel powerplant upgrades other than a secondary load controller and an electric boiler to absorb and deliver excess energy to the district heat loop (or resistive load bank to dissipate excess energy to the atmosphere). For the proposed alternative to replace one of the existing 210 kW John Deere 6090 diesel generators with a smaller 101 kW John Deere 4045 diesel, an extra cost must be added. Because this upgrade would be fixed cost regardless of wind project capacity size, $150,000 is added to the kilowatt cost (1.3 x $10,897) for the alternate diesel generation wind project configurations.

Estimated Egegik wind power project costs; proposed upgrade with JD 4045 diesel generator

Configuration	No. Turbs.	Turbine Capacity (kW)	Project Cost Estimate
Bergey 10	2	20	$ 433,322
Eocycle EO25	1	25	$ 504,153
Eocycle EO25	2	50	$ 858,305
NPS100-24	1	95	$ 1,495,780
XANT M-24	1	95	$ 1,495,780

Fuel Cost

A fuel price of $5.65/gallon was used in the economic evaluation via reference to the AEA's 2015 *EvaluationModelREFR9Final (1)* Excel spreadsheet. This price reflects the average estimated fuel price in Egegik between the 2018 (the assumed project start year) fuel price of $4.98/gallon and the 2036 (20-year project end year) fuel price of $6.54/gallon using diesel fuel price projection in the spreadsheet. This price projection includes an average CO_2-equivalent allowance cost of $0.67/gallon.

[15] Funded via AEA's Renewable Energy Fund. Conceptual designs include more thorough and accurate cost estimates than do feasibility studies.

The average Egegik fuel price for the economic valuation model compares to a fuel cost of $3.87/gallon reported to Alaska Energy Authority for the FY 2016 Power Cost Equalization program. Note that this price equates to $4.36 when a $0.49 CO_2-equivalent allowance cost (for 2016) is included.

AEA general economic model assumptions (2015 REF9 spreadsheet)

Economic Assumptions	
Project life	20 years (2018 to 2037)
Discount rate	3%
Diesel Generators	
O&M cost	$0.203/kWh
Fuel cost	$5.65/gallon
Diesel fuel efficiency	13.0 kWh/gal
Wind Turbines	
O&M cost	1% of capital cost/year

Economic Valuation

As previously noted, HOMER software was used in this wind power feasibility study to model the wind resource, wind turbine energy production, effect on the diesel engines when operated with wind turbines, and excess wind energy that could be used to serve thermal loads (or dissipated to atmosphere). Although HOMER software is designed to evaluate economic valuation by ranking alternatives, including a base or “do nothing” alternative by net present cost, this report makes use of Alaska Energy Authority methodology which differs in its assumptions of O&M costs, fuel cost for each year of the project life, and disposition of excess energy. Excess energy is valued by Alaska Energy Authority methodology with an assumption that the power plant is not co-generation. In other words, excess energy is valued without consideration of possible thermal production loss due to reduced diesel engine loading as would occur in a co-generation system configuration.

To align economic valuation of project alternatives with Alaska Energy Authority methods, this feasibility study uses their economic evaluation methods, which is reasonably accurate for Egegik in that the presumed low thermal load of Fisherman’s Hall would likely still be served even with reduced diesel generator heat output due to lower engine loading. With that, routing excess wind energy to an electric boiler in the district heat loop is not necessary. Excess energy then has no use and hence is not valued in the economic analysis.

Project Economics, Existing Powerplant

Noted several times in this report is that the existing powerplant is oversized for the existing electric load profile and poorly suited for the introduction of wind power due to insufficient margin between load demand and minimum diesel engine loading. This dynamic is seen with the very high excess electricity modeled for the four turbine configuration options evaluated. This dynamic is also apparent with the following economic valuation table which indicates poor economic viability by reference to low B/C (benefit-to-cost) ratios.

Project economic valuation, existing power plant[16]

Turbine Configuration	Wind Power Capacity (kW)	(times one thousand) NPV Costs	NPV Benefits	B/C ratio	Diesel Saved (gal/yr)
2 Bergey 10's	20	$ 283.3	$ 93.5	0.33	1,247
Eocycle EO25	25	$ 354.1	$ 144.4	0.41	1,787
NPS100-24	95	$1,345.8	$ 516.5	0.38	6,523
XANT M-24	95	$1,345.8	$ 526.8	0.39	6,609

Project Economics, Alternate Powerplant with 101 kW Diesel Generator

This report has proposed replacing one of the existing 210 kW John Deere 6090 diesel with one or two much smaller 101 kW John Deere diesel generators. Even though, by itself, the John Deere 4045 is less efficient at 75 percent loading as the John Deere 6090, for wind-diesel applications the smaller diesel creates more margin between electric load demand and 20 percent minimum diesel loading, enabling much greater application of wind power to service the electric load. This is seen in the earlier *summary table of wind power options, with 101 kW diesel generator* which demonstrates much less excess energy that must be dissipated and wasted.

The significantly more efficient use of wind power to serve the electric load when paired with a smaller diesel generator is clear in the following economic valuation table, which presents much higher benefit-to-cost ratios, including four over 1.0, indicating that these configurations may be economically beneficial, presuming that underlying assumptions are accurate and/or achievable.

Project economic valuation, with John Deere 4045 diesel generator

Turbine Configuration	Wind Power Capacity (kW)	(times one thousand) NPV Costs	NPV Benefits	B/C ratio	Diesel Saved (gal/yr)
2 Bergey 10's	20	$ 433.3	$ 391.1	0.90	3,967
Eocycle EO25	25	$ 504.1	$ 536.5	1.06	5,292
2 Eocycle EO25's	50	$ 858.3	$ 951.6	1.11	9,326
NPS100-24	95	$1,495.8	$1,551.6	1.04	15,367
XANT M-24	95	$1,495.8	$1,543.1	1.03	15,295

The reader of this report is cautioned, however, that the economic valuations are AEA's default installed cost assumptions (with a 30% adjustment applied), not actual construction cost estimates, the latter of which are beyond the scope of this study. The same applies to the $150,000 cost estimate to replace one of the existing John Deere 6090 diesel generators in the powerplant with a John Deere 4045. This replacement cost is based on informal conversations with Alaska Energy Authority; further review and scrutiny are recommended.

[16] NPV = net present value; B/C = benefit-to-cost ratio, calculated as NPV Benefits divided by NPV Costs

Regarding assumptions, note that wind turbines are estimated at 85 percent net annual energy production. This would a reasonable – or quite low – assumption for grid-connected, utility-scale wind projects, but is much higher than has been experienced to date in rural Alaska. The reasons for this are many and the reader again is cautioned to bear in mind the assumptions of these analyses.

Geotechnical Conditions

Public resource reference texts and documentation of geological conditions in the Egegik area are not extensive, representing perhaps the lightly populated nature of the region. One particularly useful reference, however, is *Permafrost and Ground Water in Alaska*, Geological Survey Professional Paper 264-F, by David Hopkins, Thor Karlstrom, and others, published in 1955 with a second printing in 1982.

In the Bristol Bay Region of this paper, following is pertinent text related to general conditions of Egegik: "The Nushagak River lowland is a broad bedrock basin partly filled with unconsolidated glacial and glacial-fluvial materials derived from adjacent uplands. …Intrusive and extrusive igneous rocks predominate in the mountains east of the lowland."

"The Alaska Peninsula consists of a broad anticline of gently folded and faulted sediments intruded by fine- and course-textured igneous rocks… The lowlands are underlain by course-textured, unconsolidated materials, including glacial till and outwash sand, gravel and silt… Windblown silt mantles much of the surface of the Alaska Peninsula and Nushagak River lowlands."

"The climate of the Bristol Bay region is marginal for the formation and preservation of frozen ground. The probability of encountering microclimates…favorable for the development of permafrost decreases southward down the Alaska Peninsula. Areas beyond Egegik are considered to be in the no-permafrost zone."

"Frozen ground in lowlands of the…region is chiefly found in silt…but it also occurs in fine sand glacial till. Shallow permafrost is found most commonly beneath swampy lowlands. Permafrost generally is absent in course-textured materials and in areas of moderate relief…"[17]

Geological/geotechnical conditions more directly specific to Egegik are documented in a February 2013 Golder Associates technical report, *Geotechnical Exploration and Foundation Recommendations for Proposed Power Plant Upgrades: Egegik, AK,* commissioned by Alaska Energy and Engineering for Alaska Energy Authority's new diesel powerplant that was completed in 2014. Test pits at the power plant site (see page 5 of this report for map indicating relative locations of the met tower site and the powerplant) were excavated to 12 and 16 feet in November 2012. Golder's report states the following: "The subsurface conditions of the text pits showed 2 to 10 feet of fill covered the site… A layer of organic silt about 4.5 feet thick was observed in both text pits… The organic silt layer had varying amounts of sand and fine fibrous organics. Mineral silt with medium plasticity was observed underlying the organic silt…and was present to test pit termination depth."

[17] Hopkins and Karlstrom, Permafrost and Ground Water in Alaska, page 132

"Egegik is in a region of Alaska where frost is not expected to extend to significant depths. Estimated frost penetration depths are 4 to 4.5 feet…"[18]

The Golder report validates the general near-surface geological conditions in Egegik described by the 1955 Geological Survey paper and addresses specific issues of relevance for design and construction of the new powerplant. Should village-scale (i.e., 100 kW and larger turbines) wind power be developed in Egegik, subsurface exploration work to obtain site-specific data from turbine foundation design will be commissioned. This work, of course, will be accomplished at the site chosen for wind turbines, which as noted elsewhere in the report may not be the location of the met tower. It is anticipated, however, that geological conditions at a wind turbine site will not substantially differ from that documented by Golder Associates, although borings deeper than 16 feet would be necessary to support turbine foundation design data needs.

Recommendations

Wind power holds potential as a possible renewable energy option for Egegik, provided the powerplant is re-equipped with at least one smaller diesel generator, such as a 101 kW John Deere 4045. This is necessary to provide additional margin between electric load demand and minimum diesel loading. Alaska Energy Authority, however, indicated that market availability of the more desirable Model Year 2013 Tier 3 version of the 4045 may be very limited, so if considered, a wider assessment of diesel options to provide similar compatibility with wind power is strongly encouraged.

Modeling indicates that the met tower site has the strongest winds, or nearly so, throughout Egegik, but winds at several suggested alternate sites are also very strong, so considerations such as proximity to existing electrical distribution, which is lacking at the met tower site, may take precedence. With this, Alaska Energy Authority's alternate site, the powerplant or the west runway lobe of the old airport may be more optimal choices for wind turbine siting.

This feasibility study did not include a detailed discussion of the integration challenges of wind power at higher penetration. Apart from very low wind penetration of perhaps only 10 kW, which was not analyzed, some manner of integration will be required to avoid turbine dispatch control. This could include a secondary load controller and load bank to control frequency and dissipate excess energy to the atmosphere, or even lithium ion storage batteries with a grid-forming converter to enable diesels-off operations. Note that this feasibility study did not evaluate the energy savings potential nor costs of battery storage.

The benefits of renewable energy development with the displacement of diesel fuel usage can be considerable, but with benefits come costs beyond capital expenses. Wind-diesel power systems are more complex than diesel-only systems and the community must be prepared to accept the inherent challenges. These include additional training for system operators, the need for service contracts to maintain the turbines, a willingness to test and determine most efficient operating modes, and a

[18] Golder Associates Geotechnical report for powerplant upgrades: Egegik, pages 2-3

willingness to troubleshoot inevitable problems. This requires a commitment to human capacity development and growth that should be considered carefully before embarking a development program.

Caveats and precautions aside, modeling conducted for this feasibility study indicates the potential for wind power development in Egegik. Community residents and other interested stakeholders are encouraged to learn more about wind power and perhaps consider funding a more detailed preliminary design to better define integration needs and costs.

Appendix A – Egegik Wind Resource Assessment Report

Egegik, Alaska Wind Resource Assessment Report

Egegik met tower, photo by Douglas Vaught

February 23, 2017

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Summary

The wind resource measured at the Egegik met tower site is outstanding with a mean annual wind speed of 7.43 m/s and a wind power density of 516 W/m^2 at 34 meters above ground level. In all respects the Egegik wind resource is highly suitable for wind power development. This wind resource assessment report was prepared by V3 Energy, LLC under contract to Lake and Peninsula Borough.

Met tower data synopsis

Data dates	8/20/2014 to 9/03/2016 (24.5 months)
Wind speed mean, 34 m, annual	7.43 m/s (16.6 mph)
Wind power density mean, 34 m	516 W/m^2
Wind power class	Class 5 (excellent)
Max. 10-min wind speed	32.6 m/s
Maximum 2-sec. wind gust	41.1 m/s (91.9 mph), December 2015
Weibull distribution parameters	k = 1.92, c = 8.34 m/s
Wind shear power law exponent	0.216 (moderate shear)
Surface roughness	0.28 meters (agricultural land with tall hedgerows)
IEC 61400-1, 3rd ed. classification	Class III-C
Turbulence intensity, mean (at 34 m)	0.104 (at 15 m/s)
Calm wind frequency (at 34 m)	19% (< 4 m/s)

Test Site Location and Selection Process

A 34 meter NRG Systems, Inc. tubular-type meteorological (met) tower was installed in Egegik in an open area of Becharof Corporation land on a hill approximately 2,200 ft. due east of the Egegik city office. Egegik is located on the south bank of the Egegik River on the Alaska Peninsula, 100 miles southeast of Dillingham and 326 air miles southwest of Anchorage. Egegik is incorporated as a 2nd class city in the Lake and Peninsula Borough with 85 permanent residents, but its population increases significantly during early and mid-summer when the local salmon processing plant is operational. Egegik falls within the southwest climate zone, characterized by persistently overcast skies, high winds, and frequent cyclonic storms.[1]

The test site was chosen after a decision was made not to lower and re-use an existing NRG Systems 30 meter, 4-inch diameter met tower located immediately across the street (due east) of the city office. This met tower had been in place for an unknown number of years and was in acceptable condition for re-use on site, but could not be moved because corrosion of the galvanized coating caused the slip-fit tower sections to fuse. It is not known who installed this tower, when, or the subsequent fate of any data collected from it.

Following abandonment of the old met tower location, focus was directed to the highest point of land in the community, excluding the location of the GCI cellular communications tower 2,300 ft. south of the subsequently-chosen met tower site. The met tower site is on Becharof Corporation land and their

[1] Community data obtained from State of Alaska DCCED Community and Regional Affairs website

approval was obtained for temporary installation of a met tower for the two-year life of the wind study. The site is a commanding location with excellent exposure and visibility in all directions. Heavy brush exists north and east of the site, which presents some concern for wind turbine operations.

After approval of the chosen site by Alaska Energy Authority (AEA), they forwarded a suggestion to instead consider a site at the intersection of the airport road and the GCI tower access road to better locate the met tower with existing power infrastructure. This site was inspected during a pre-installation visit and was deemed undesirable for met tower installation due to heavy brush and an undesirable slope for a met tower. Additionally, landowner permission and an FAA obstruction determination had already been obtained for the chosen location. But, given the strong wind resource measured in Egegik, this alternate site could be suitable wind turbines.

Southwest Alaska and Egegik, Google Maps image

Met Tower Information

The met tower was installed in late August 2014 with highly appreciated labor and material assistance from City of Egegik.

Met tower details

Site number	5500
Latitude/longitude	N 58° 12’ 31.50”, W 157° 21’ 49.00”
Time offset	-9 hours from UTC (Yukon/Alaska time zone)
Site elevation	45 meters (148 ft.)
Datalogger type	NRG SymphoniePLUS3, 10 minute time step
Tower type	Guyed tubular, 15 cm (6 in.) diameter, 34 meter (112 ft.) height

Tower sensor information

Channel	Sensor type	Designation	SN[2]	Height	Multiplier	Offset	Orientation
1	NRG #40C anem.	34 m A	222521	33.8 m	0.744	0.40	320 T[3]
2	NRG #40C anem.	34 m B	222522	34.0 m	0.758	0.34	185 T
3	NRG #40C anem.	20 m	222523	20.4 m	0.752	0.38	320 T
7	NRG #200P vane	Direction		33.1 m	0.351	000	000 T
9	NRG #110S Temp C	Temp		2.5 m	0.136	-86.38	030 T

Met tower installation; use of bulldozer to lift the tower

Tower sensor photographs

North side, up tower

East side, up tower

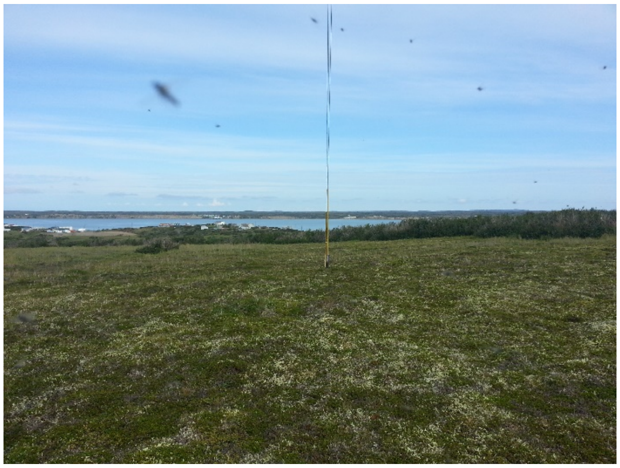
South side, up tower

West side, up tower

[2] Anemometer serial number

[3] Degrees true, or relative to Earth's geographic North Pole

Met tower site photographs



Site view to north

Site view to northeast

Site view to east

Site view to southeast

Site view to south

Site view to southwest

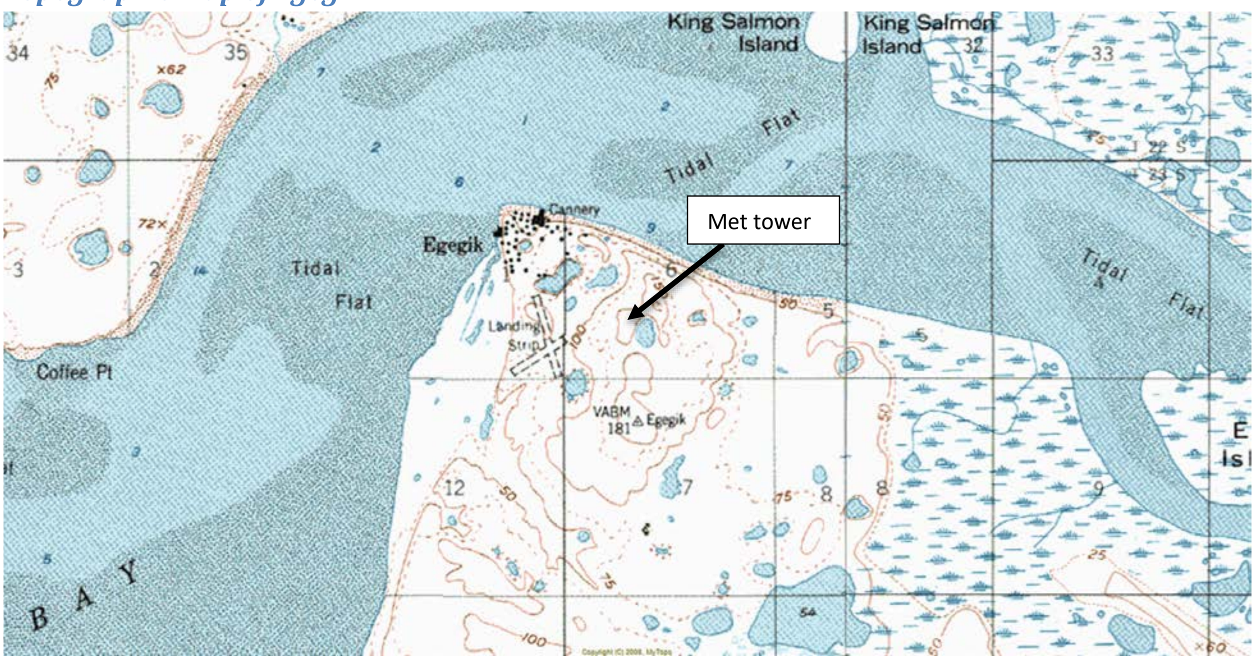
Site view to west

Site view to northwest

Egegik, view north, Google Earth image

Egegik, view south-southeast, Google Earth image

Topographic map of Egegik



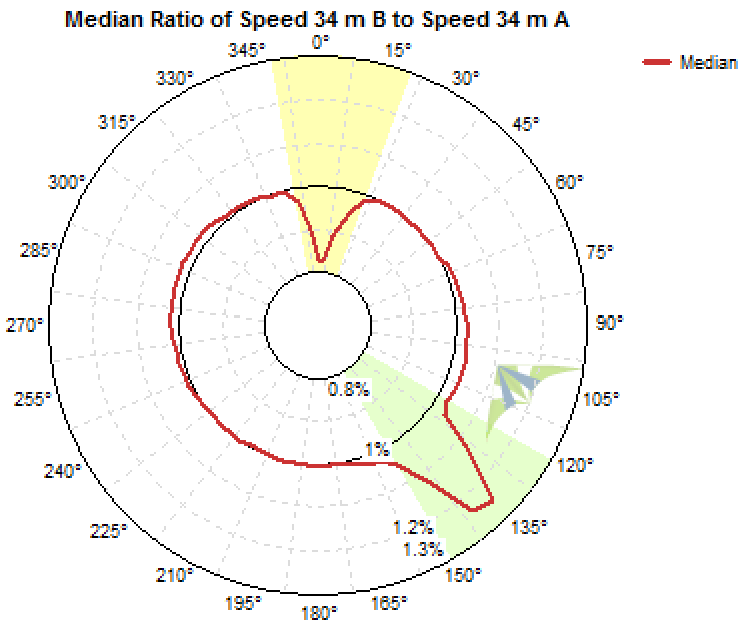
Data Quality Control

Data was filtered to remove presumed icing events that yield false zero wind speed data and non-variant wind direction data. Data that met criteria listed below were automatically filtered. In addition, data was manually filtered for obvious icing that the automatic filter didn't identify, and invalid or low quality data for situations such as logger initialization and other situations.

- Anemometer icing – data filtered if temperature < 1°C, speed SD = 0, and speed changes < 0.25 m/s for minimum 2 hours
- Vane icing – data filtered if temperature < 1°C and vane SD = 0 for minimum of 2 hours
- Tower shading of 34 meter A and B paired anemometers – data filtered when winds from ± 15° of behind tower; refer to graphic below

In general, icing conditions were infrequent indicating minimal concern for wind turbine energy production loss due to ice. With frequent southeasterly winds, tower shadow affected anemometer 34 m A (channel 1, oriented to 320° T) much more often than anemometer 34 m B (channel 2, oriented to 185° T), hence the significantly lower recovery rate of anemometer 34 m A.

Tower shading plot



Sensor data recovery table

Data Column	Possible Records	Valid Records	Recovery Rate	Icing	Invalid	Tower shading
Speed 34 m A	107,322	83,265	77.6%	1,927	197	21,793
Speed 34 m B	107,322	97,663	91.0%	1,632	198	7,880
Speed 20 m	107,322	105,077	97.9%	1,906	195	0
Direction 34 m	107,322	103,168	96.1%	3,804	206	0
Temperature	107,322	106,983	99.7%	0	195	0

Sensor data recovery rate by month (includes tower shading for 34 m A & B)

Year	Month	34 m A	34 m B	20 m	Vane	Temp
2014	Aug	82.5	83.6	88.7	88.1	88.7
2014	Sep	86.3	87.3	100.0	100.0	100.0
2014	Oct	91.1	75.1	100.0	100.0	100.0

Year	Month	34 m A	34 m B	20 m	Vane	Temp
2014	Nov	74.7	92.5	99.7	86.5	100.0
2014	Dec	75.1	96.8	95.2	86.5	100.0
2015	Jan	72.4	72.5	78.7	69.9	100.0
2015	Feb	76.5	87.7	96.4	94.9	100.0
2015	Mar	75.7	84.9	92.6	92.3	100.0
2015	Apr	80.6	87.7	100.0	100.0	100.0
2015	May	38.7	96.7	100.0	100.0	100.0
2015	Jun	80.7	96.7	100.0	100.0	100.0
2015	Jul	76.0	98.1	100.0	100.0	100.0
2015	Aug	89.1	89.7	100.0	100.0	100.0
2015	Sep	89.3	86.5	100.0	100.0	100.0
2015	Oct	83.9	88.5	100.0	100.0	100.0
2015	Nov	85.0	94.3	100.0	96.8	100.0
2015	Dec	77.6	91.7	98.5	93.4	100.0
2016	Jan	77.8	92.8	96.8	96.8	96.8
2016	Feb	80.9	95.7	97.3	97.4	100.0
2016	Mar	84.3	85.9	98.4	96.1	100.0
2016	Apr	61.2	97.5	100.0	100.0	100.0
2016	May	67.0	98.0	100.0	100.0	100.0
2016	Jun	83.3	97.5	100.0	100.0	100.0
2016	Jul	88.0	98.2	100.0	100.0	100.0
2016	Aug	68.4	94.3	100.0	100.0	100.0
2016	Sep	43.6	98.8	100.0	100.0	100.0
All Data		77.6	91.0	97.9	96.1	99.7

Data Synthesis

Filtering removes compromised sensor readings from the data set. This is desirable for icing in that it eliminates the negative speed bias of false "zero" data. Filtering for tower shadow is more nuanced in that filtered results bias both paired anemometers, but it's not obvious in which direction for either. One solution is to remove filtered data and fill the missing gaps with synthesized data using a gap-filling subroutine[4] contained in Windographer Pro software. Gap-filling, or data synthesis, yields more a more representative and realistic data set. This is especially true for tower shadow-filtered data in that the flagged data from one paired anemometer can be reconstructed with data from the other anemometer of the pair. The result is a true representation of wind speeds from both paired anemometers. Gap-filling icing-flagged data is more complex in that often all anemometers and/or wind vanes freeze simultaneously and hence Windographer software must use the Markov transition to create a probable result for the flagged period. For short icing periods, the inherent uncertainty of this approach is low; for long periods, it is higher.

[4] First-order Markov transition matrix; described in Windographer Help

Wind Speed

Anemometer data obtained from the met tower, from the perspectives of both mean wind speed and mean wind power density, indicate a moderate wind resource. Note that cold temperatures contributed to a higher wind power density than standard conditions would yield for the measured mean wind speeds. This is reflected in the CRMC (cubed root mean cubed) wind speed, which reflects a calculation of a steady wind speed, at the measured mean air density, that would yield the measured mean wind power density. In other words, given the cool climate in Egegik, the winds punch above their weight.

A table following that below presents the same data but with anemometer icing and tower shadow data removed from the data set and then synthesized with Windographer software's gap-filling subroutine. The advantage of gap-filling is that a more representative data set is achieved, especially with inclusion of data from the opposing anemometer (with paired anemometers) when data is filtered for tower shadow (gap-filling synthesizes tower shadow data by referencing the paired anemometer where data is not flagged).

Anemometer data summary (gap-filled)

Variable	Speed 34 m A	Speed 34 m B	Speed 20 m
Measurement height (m)	33.8	34.0	20.4
Mean wind speed (m/s)	7.36	7.41	6.60
MoMM[5] wind speed (m/s)	7.38	7.43	6.61
Max 10 min avg. wind speed (m/s)	32.6	32.6	30.0
Max gust wind speed (m/s)	41.1	38.7	40.8
CRMC wind speed (m/s)	9.24	9.32	8.27
Weibull k	1.94	1.92	1.97
Weibull c (m/s)	8.29	8.34	7.44
Mean power density (W/m^2)	498	511	357
MoMM power density (W/m^2)	503	516	361
Mean energy content ($kWh/m^2/yr$)	4,359	4,475	3,129
MoMM energy content ($kWh/m^2/yr$)	4,403	4,519	3,159
Energy pattern factor	1.98	1.99	1.97
Frequency of calms (<4 m/s) (%)	19.8	19.9	24.3

Time Series

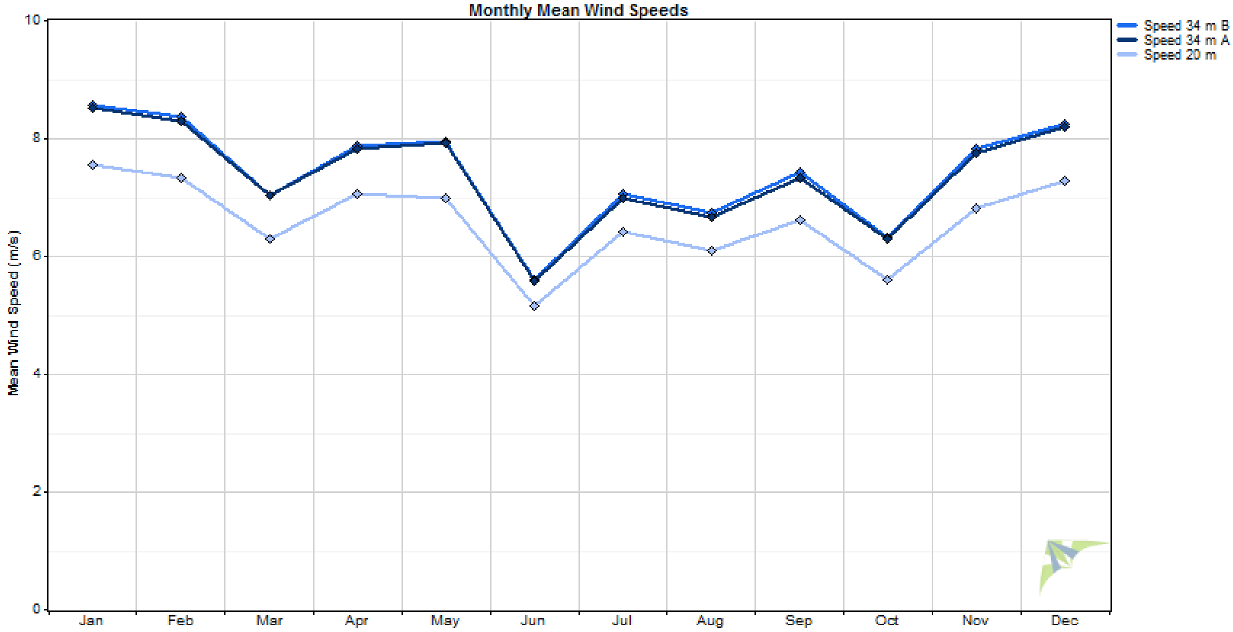
Time series calculations indicate higher wind speeds during the winter months compared to summer month, but this difference is not highly pronounced. The daily wind profile (annual basis) indicates higher wind speeds during the day with peak winds occurring between 3 and 4:00 p.m.

[5] MoMM: mean of monthly means, or annual

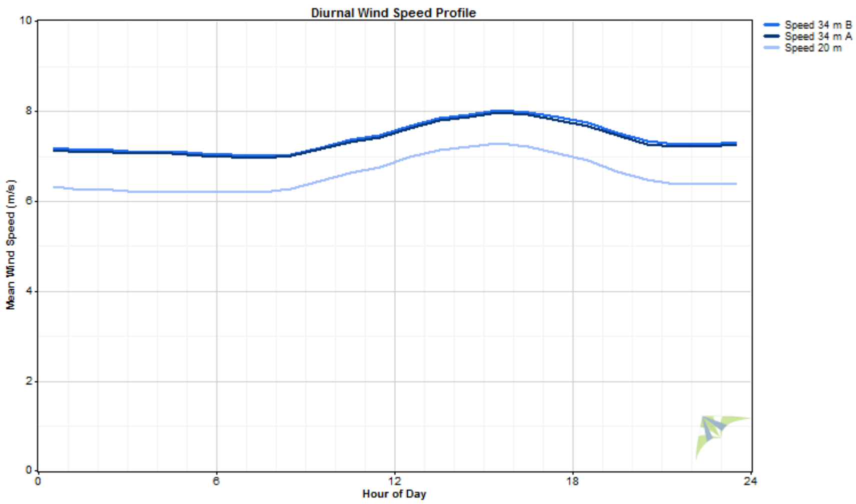
34 m B anemometer data summary

Year	Month	Raw Mean (m/s)	Filtered Mean (m/s)	Gap-filled Mean (m/s)	Max 10-min Avg (m/s)	Max Gust (m/s)	Std. Dev. (m/s)	Weibull k (-)	Weibull c (m/s)
2014	Aug	6.68	6.79	6.71	14.4	19.0	2.72	2.62	7.53
2014	Sep	7.40	7.52	7.51	22.4	28.0	4.00	1.92	8.44
2014	Oct	6.14	6.26	6.38	15.9	19.9	3.02	2.19	7.17
2014	Nov	7.04	7.24	7.08	22.0	28.0	3.89	1.87	7.96
2014	Dec	7.77	7.94	7.88	28.0	34.6	4.78	1.74	8.88
2015	Jan	6.34	7.82	7.89	18.7	25.7	3.26	2.55	8.87
2015	Feb	7.87	7.98	8.15	23.9	31.8	3.81	2.26	9.20
2015	Mar	7.04	7.69	7.61	19.2	24.6	3.49	2.31	8.58
2015	Apr	7.65	7.87	7.74	20.2	25.7	3.90	2.09	8.74
2015	May	8.98	9.17	8.99	23.4	29.2	4.92	1.87	10.10
2015	Jun	5.79	5.87	5.81	19.6	24.6	3.17	1.90	6.54
2015	Jul	6.89	6.99	6.90	22.6	28.0	3.93	1.81	7.75
2015	Aug	7.13	7.34	7.19	16.7	20.7	3.25	2.35	8.12
2015	Sep	7.49	7.59	7.58	21.7	28.0	3.90	2.02	8.54
2015	Oct	6.19	6.16	6.29	16.0	19.9	3.22	1.91	7.00
2015	Nov	8.60	8.64	8.62	21.9	28.0	3.85	2.38	9.72
2015	Dec	8.48	8.89	8.62	32.6	41.1	5.57	1.58	9.60
2016	Jan	9.15	9.29	9.17	26.7	34.6	4.28	2.25	10.34
2016	Feb	8.41	8.64	8.58	20.4	26.8	3.79	2.40	9.66
2016	Mar	6.43	6.42	6.53	19.5	23.6	4.22	1.47	7.16
2016	Apr	8.02	8.13	8.04	22.9	28.0	4.16	2.02	9.07
2016	May	6.93	7.00	6.94	18.9	24.6	3.63	2.00	7.83
2016	Jun	5.43	5.49	5.44	20.1	25.7	3.49	1.62	6.08
2016	Jul	7.24	7.27	7.25	16.8	19.9	3.35	2.30	8.17
2016	Aug	6.31	6.41	6.34	15.9	19.9	2.98	2.24	7.15
2016	Sep	5.05	5.09	5.05	10.6	14.2	2.35	2.31	5.71
All Data		7.26	7.47	7.41	32.6	41.1	3.98	1.92	8.34
Annual		7.27	7.48	7.43					

Monthly time series (annual), mean wind speeds (gap-filled data set)



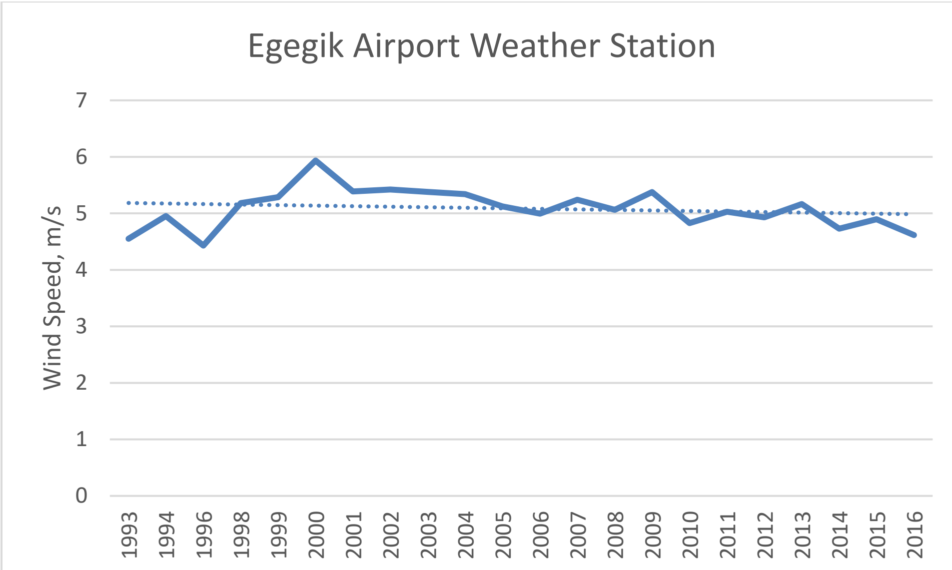
Daily wind profile (gap-filled data set)



Long-term Wind Speed Average

Comparing the 24 months of measured wind speed data at the Egegik met tower is possible by reference to the nearby Egegik Airport automated weather station. Data for this station was obtained for the time period of June 1993 through Dec. 31, 2016. For this 27.5 year time period, the AWOS station recorded an average wind speed of 5.09 m/s (at a 10 meter measurement height). In 2015, which comprises the only full calendar year of the Egegik met tower operating time period, the AWOS station wind speed average was 4.89 m/s, which is 4% less than the long-term average. Note also a very slight declining trend in wind speed over the 27.5 year period, although this data trend is mostly driven by high wind speed variability from 1993 to 2000. Since 2000, winds at the Egegik Airport have been fairly constant.

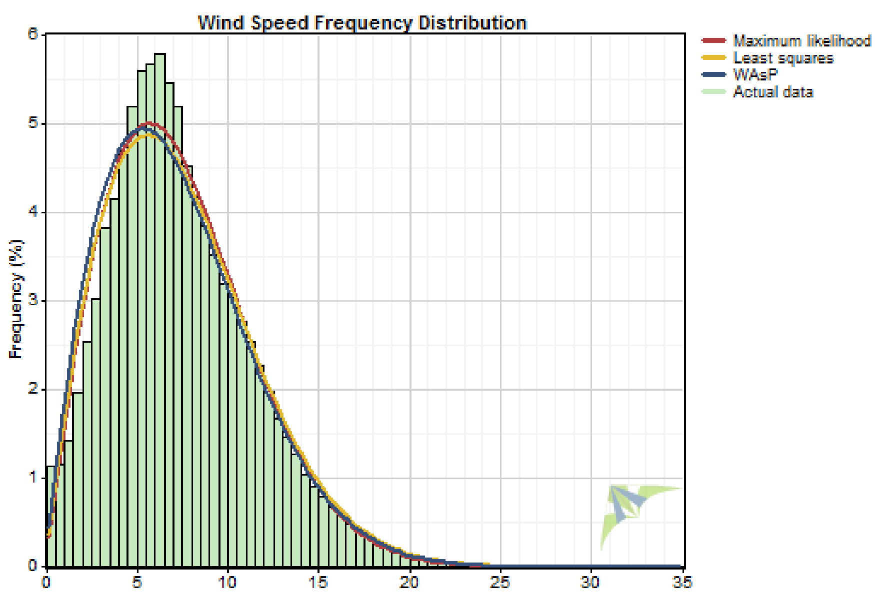
Egegik Airport wind speed



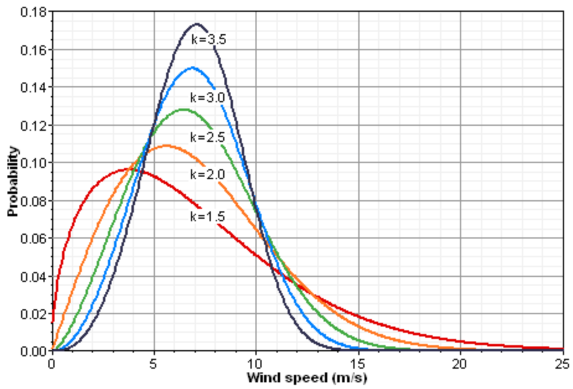
Probability Distribution Function

The probability distribution function (PDF), or histogram, of the Egegik met tower site wind speed indicates a shape curve dominated by moderate wind speeds and is mostly reflective of a "normal" shape curve, known as the Rayleigh distribution (Weibull k = 2.0), which is defined as the standard wind distribution for wind power analysis. As seen below in the wind speed distribution of the 34 meter B anemometer, the most frequently-occurring wind speeds are between 4 and 8 m/s with few wind events exceeding 20 m/s, the cutout speed of most wind turbines. Also, note the accompanying cumulation distribution with respect to the infrequency of very high wind speeds in Egegik.

PDF of 34 m B anemometer (gap-filled)



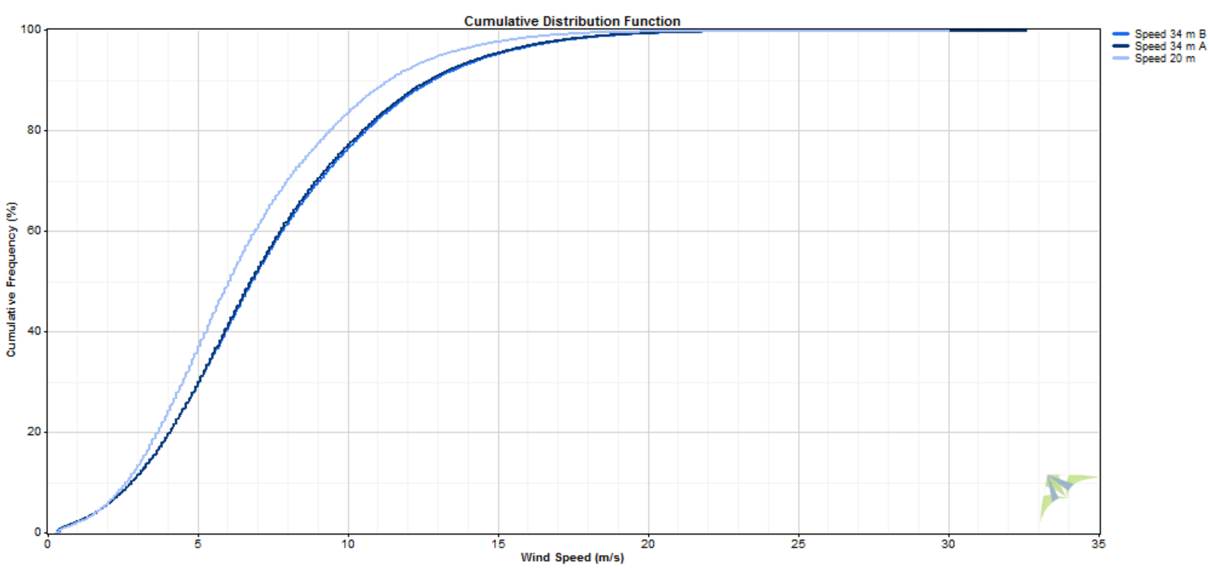
Weibull k shape curve table



Weibull values table, 34m B anemometer

Algorithm	Weibull k	Weibull c (m/s)	Mean (m/s)	Proportion Above 7.41 m/s	Power Density (W/m2)	R Squared[6]
Maximum likelihood	1.92	8.34	7.39	0.451	493.1	0.981
Least squares	1.87	8.42	7.47	0.455	524.1	0.976
WAsP	1.83	8.19	7.28	0.435	495.5	0.971
Actual data			7.41	0.435	495.5	

Cumulative distribution



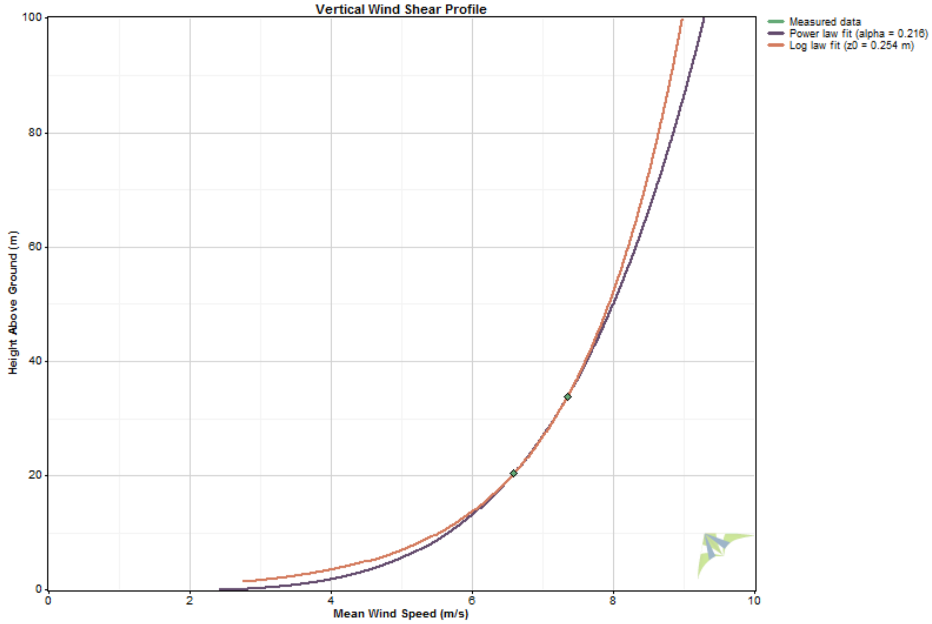
Wind Shear and Roughness

Wind shear at the Egegik met tower site was calculated with the 34 m A and 20 m anemometers, both of which were oriented toward 320° T. The calculated power law exponent of 0.216 indicates a moderate

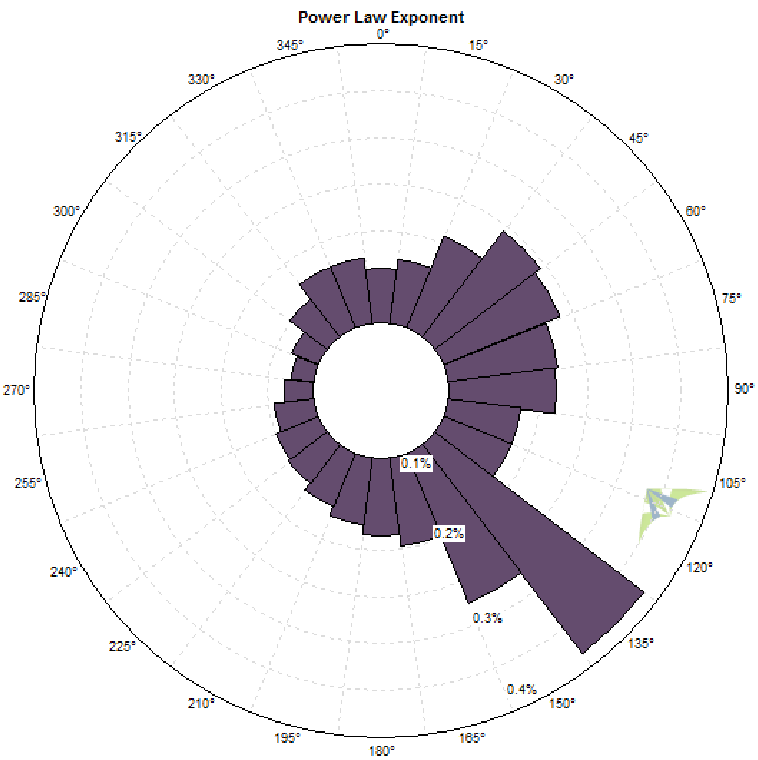
[6] Relatedness or correlation of Weibull approximation algorithm with actual data

wind shear at the site. Calculated surface roughness at the site is 0.29 m (the height above ground where wind speed would be zero) for a roughness class of 2.88 (description: agricultural land). Note the high shear with southeasterly winds, undoubtedly due to upwind brush. Mitigation should be considered if wind turbines are located at or near this site, such as removal of the brush.

Vertical wind shear profile



Wind shear by direction graph



Extreme Winds

International Electrotechnical Commission (IEC) 61400-1, 3rd edition extreme wind probability classification is one criteria – with turbulence the other – that describes a site with respect to suitability for wind turbine models. Extreme wind is described by the 50 year V_{ref}, or reference velocity in a 50 year return period; in other words, V_{ref} is the wind speed (10-minute average) predicted to occur once every 50 years.

IEC 61400-1 extreme wind classification

IEC 61400-1, 3rd ed.	
Class	V_{ref}, m/s
I	50
II	42.5
III	37.5
S	designer-specified

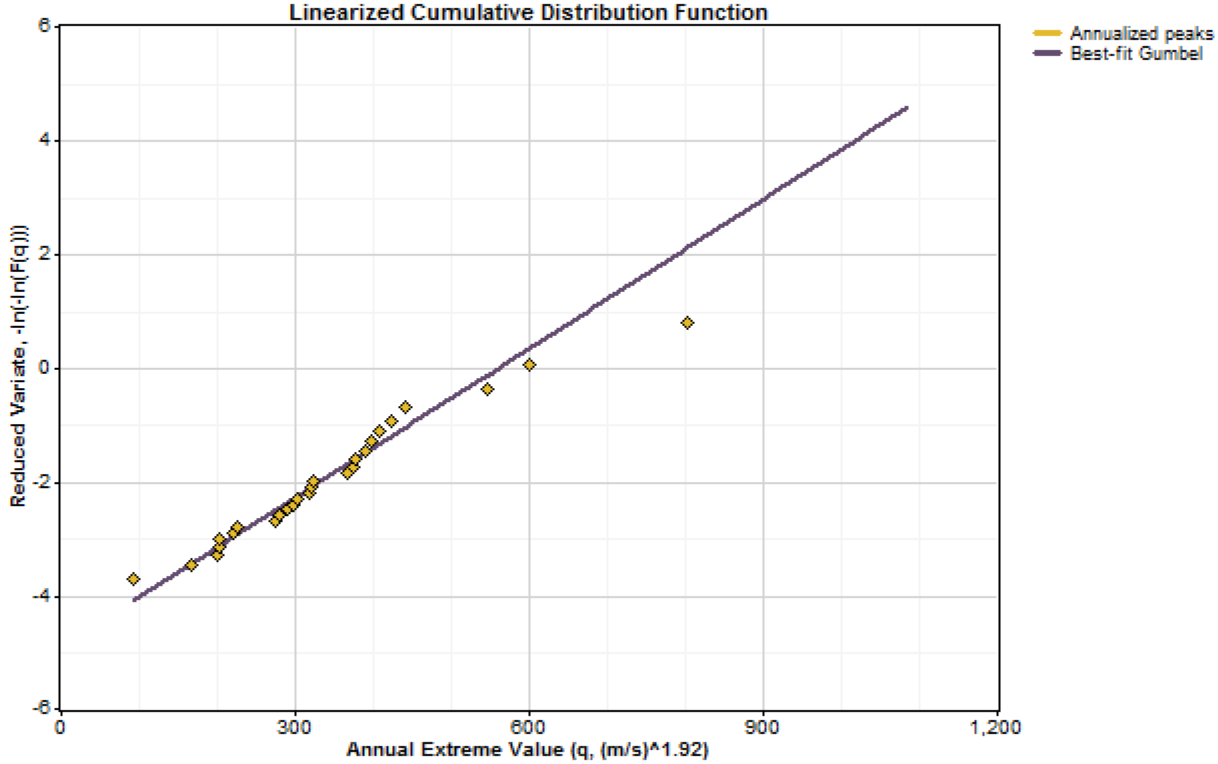
Periodic Maxima

One method to estimate V_{ref} is a Gumbel distribution analysis modified for monthly maximum winds versus annual maximum winds, which are typically used for this calculation. Thirty-four months of wind data in the 50 meter met tower data set are acceptable for this analysis, although, as noted previously, the latter months of that data set were compromised by sensor failure and all sensors were compromised by icing during the winter months.

For this analysis, the 34 meter level B anemometer is referenced because it recorded the highest wind speeds of the three anemometers on the tower. With filtered, gap-filled, and preconditioned[7] (by the Weibull k value as an exponent) data, the predicted V_{ref} by this method is 36.6 m/s. This result meets IEC 3rd edition Class III criteria, the lowest-defined category of extreme wind probability. Note, however, the presumed substantial loss of higher speed winter anemometer data due to icing. Given the comparison of measured and filtered mean wind speed to the AWS Truepower model, it is possible that V_{ref} may be higher than calculated.

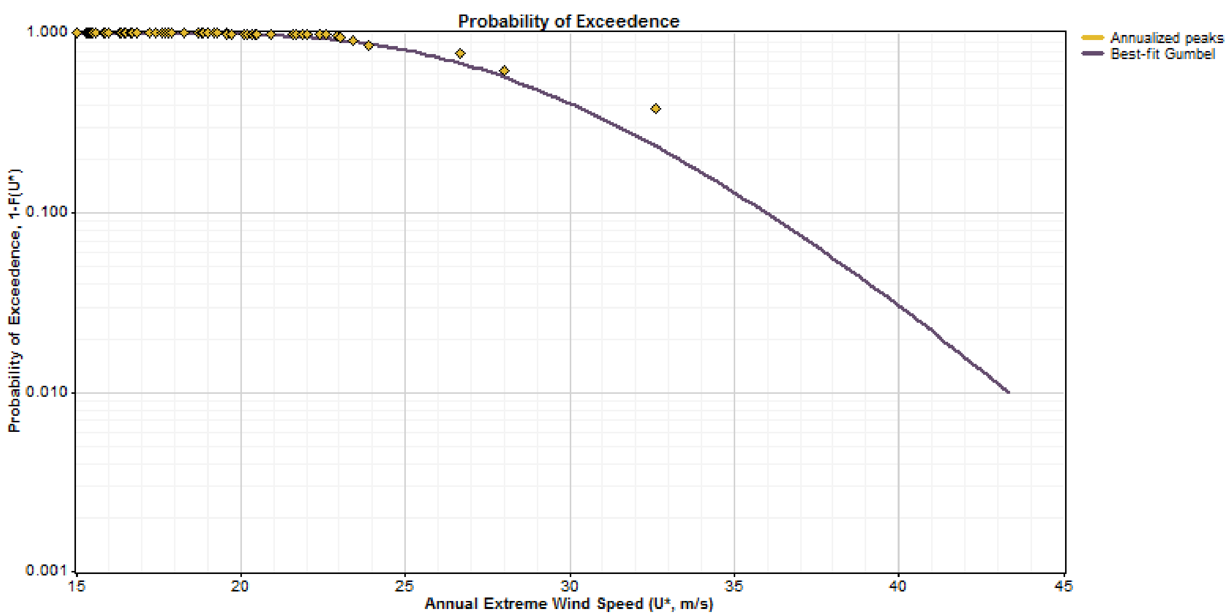
[7] Preconditioning improves the accuracy of 50-year extreme wind speed estimates; Windographer Help (references 1996 (Harris) and 2009 (Langreder et al.) studies).

Periodic maxima cumulative distribution, 34 m B anemometer



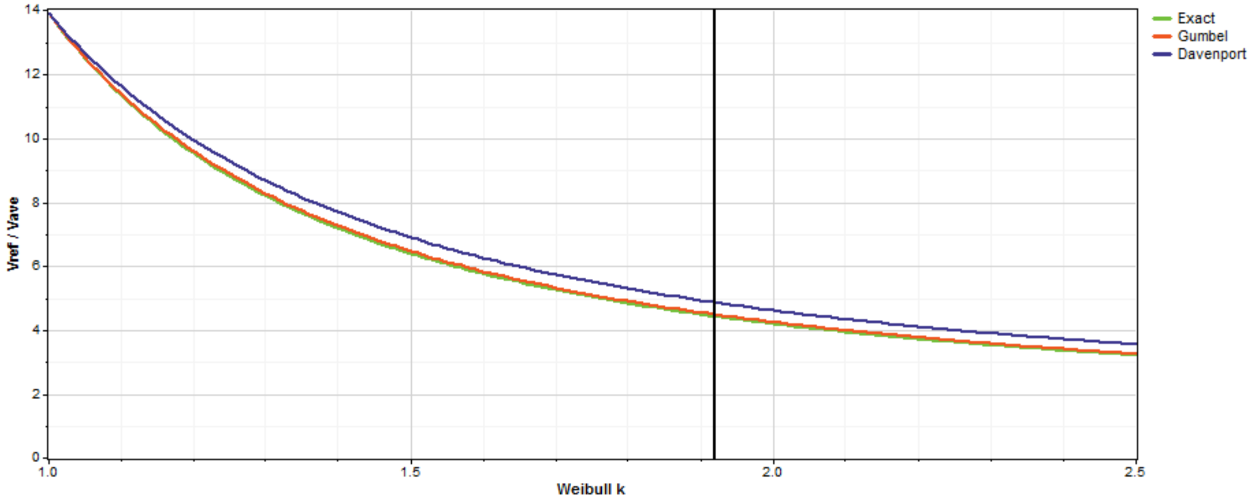
A second technique, Method of Independent Storms, yields a V_{ref} estimate of 41.2 m/s, higher than that predicted by the periodic maxima method but still within the classification constraint to classify as IEC 61400-1 Class II extreme wind.

Method of Independent Storms



A third method, known as EWTS II (European Wind Turbine Standards II), ignores recorded peak wind speeds and calculates V_{ref} from the Weibull k factor. There are three variations of this method – Exact, Gumbel and Davenport – which yields a V_{ref} between 32.9 and 36.2 m/s for Egegik. These are in-line with the periodic maxima method and within IEC 3rd edition Class III extreme wind criteria.

EWTS II plot



Summary

The calculated V_{ref} wind speeds by the three methods described above all meet IEC 61400-1, 3rd edition criteria for Class III wind classification, which has a V_{ref} limit of 42.5 m/s. The practical importance is that turbines suitable for Egegik should be IEC 61400-1 Class II certified, or possibly Class III certified if referencing only the periodic maxima and EWTS methodology.

EWTS II table

Method	Vref (50 yr) (m/s)
Periodic Maxima	36.6
Method of Independent Storms	41.3
EWTS II (Exact)	32.9
EWTS II (Gumbel)	33.4
EWTS II (Davenport)	36.2

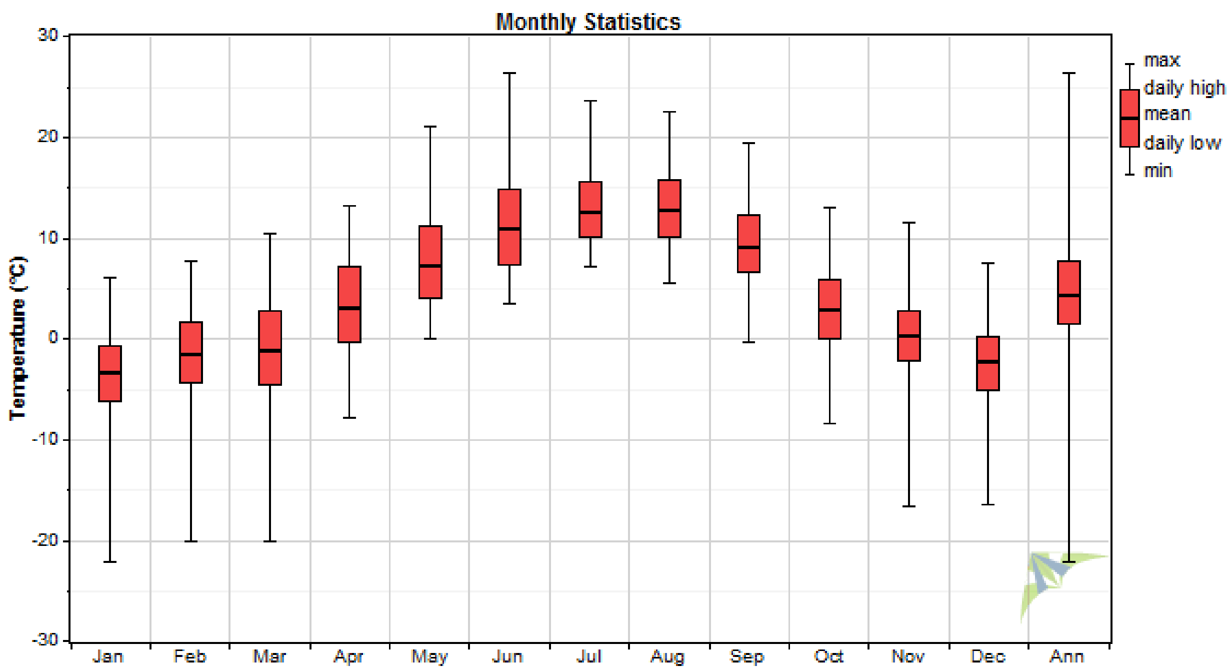
Temperature, Density, and Relative Humidity

Egegik experiences cool summers and relatively mild winters, by interior Alaska standards, with resulting higher than standard air density. Calculated mean-of-monthly-mean (or annual) air density during the met tower test period exceeds the 1.219 kg/m^3 standard air density for a 45 meter elevation by 3.6 percent. This is advantageous in wind power operations as wind turbines produce more power at low temperatures (high air density) than at standard temperature and density.

Temperature and density table

Month	Mean (°C)	Min (°C)	Max (°C)	Mean (°F)	Min (°F)	Max (°F)	Mean (kg/m3)	Min (kg/m3)	Max (kg/m3)
Jan	-3.3	-22.1	6.1	26.1	-7.8	43.0	1.300	1.216	1.399
Feb	-1.4	-20.1	7.8	29.5	-4.2	46.0	1.292	1.248	1.388
Mar	-1.0	-20.1	10.6	30.2	-4.2	51.1	1.290	1.235	1.388
Apr	3.2	-7.7	13.3	37.8	18.1	55.9	1.270	1.223	1.323
May	7.4	0.1	21.1	45.3	32.2	70.0	1.250	1.188	1.284
Jun	11.0	3.5	26.4	51.8	38.3	79.5	1.233	1.165	1.268
Jul	12.8	7.2	23.7	55.0	45.0	74.7	1.225	1.177	1.251
Aug	12.8	5.5	22.6	55.0	41.9	72.7	1.225	1.182	1.259
Sep	9.3	-0.3	19.5	48.7	31.5	67.1	1.241	1.195	1.286
Oct	3.0	-8.4	13.1	37.4	16.9	55.6	1.271	1.224	1.326
Nov	0.5	-16.6	11.6	32.9	2.1	52.9	1.283	1.231	1.369
Dec	-2.0	-16.3	7.6	28.4	2.7	45.7	1.295	1.249	1.367
Annual	4.4	-22.1	26.4	39.8	-7.8	79.5	1.264	1.165	1.399

Egegik temperature boxplot graph

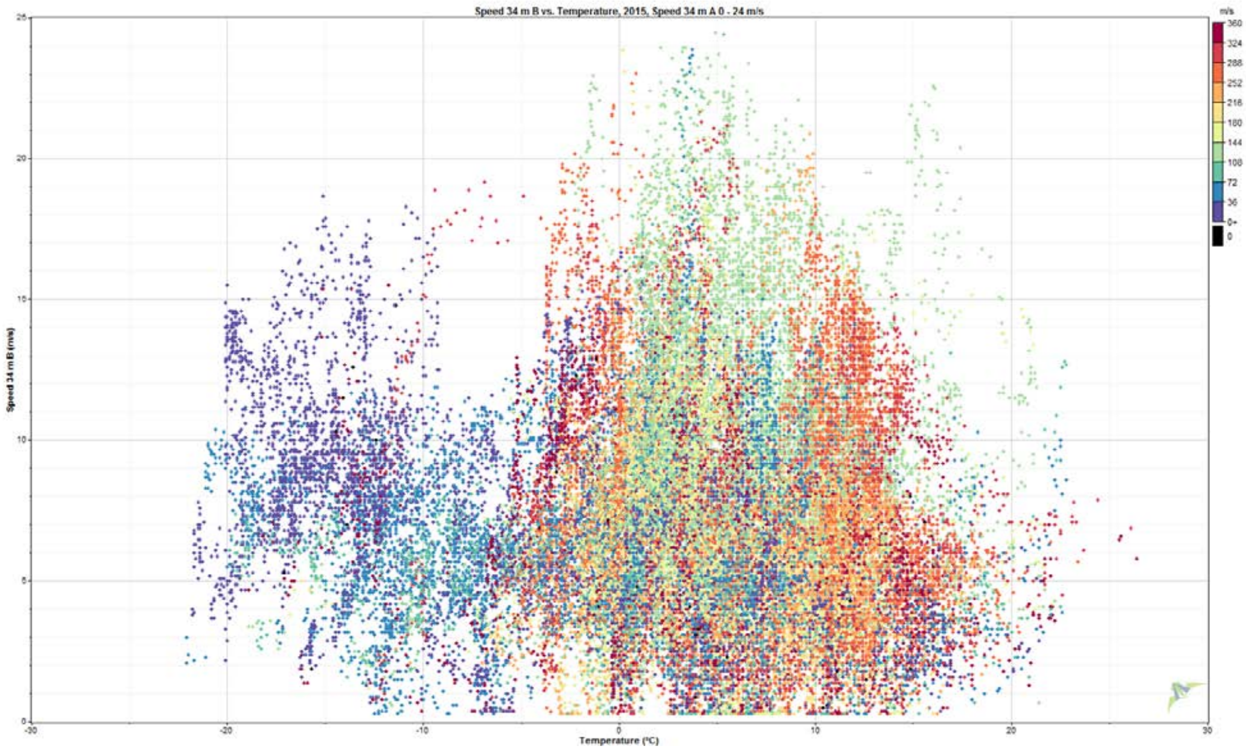


Wind Speed Scatterplot

The wind speed versus temperature scatterplot below indicates relatively cool temperatures at the Egegik met tower site but on average temperatures are above freezing, as indicated in the preceding temperate and density table. During the met tower test period, temperatures were not often colder than -20° C (-4° F), the minimum operating temperature for most standard-environment wind turbines.

With this, wind turbines with an arctic option, designed for -40° C operations, may not be necessary in Egegik.

Wind speed/temperature (color code indicates wind direction)

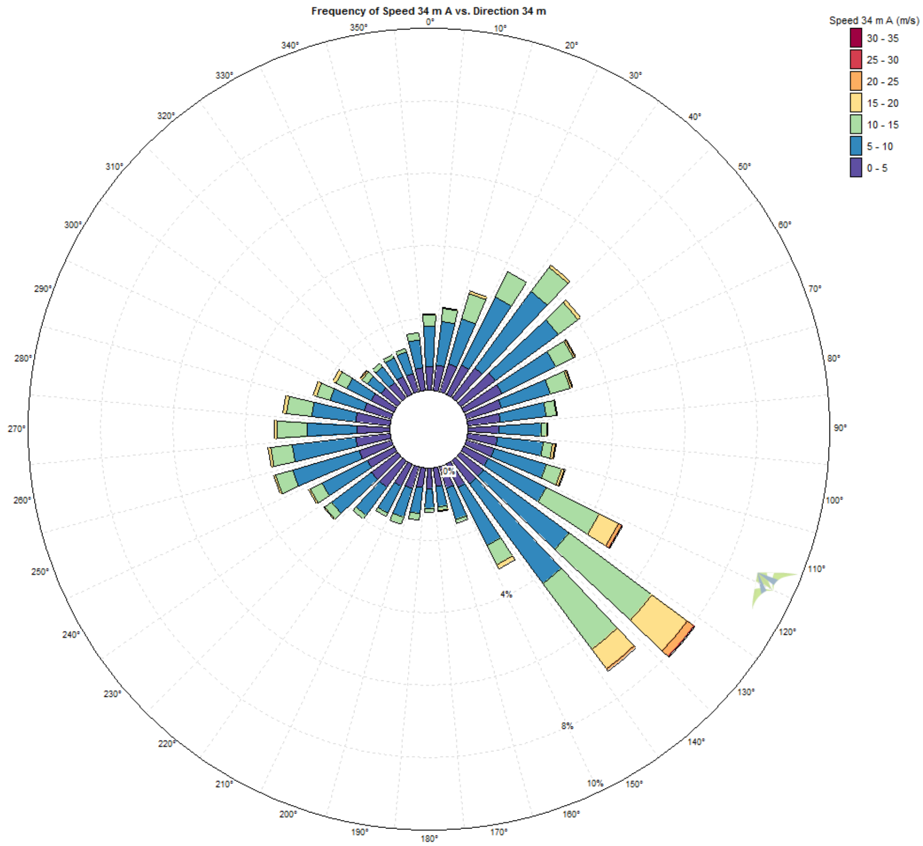


Wind Direction

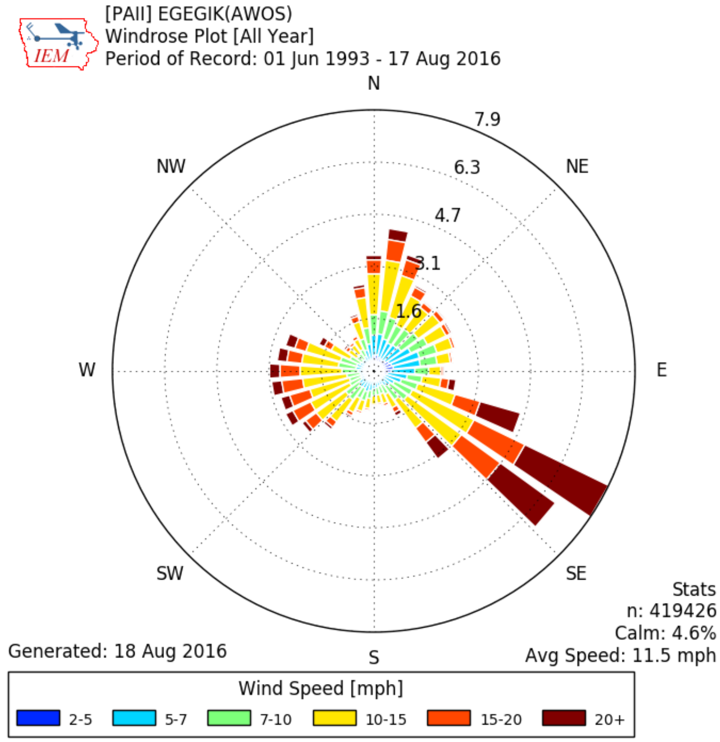
Wind frequency rose data indicates that winds at the Egegik met tower site are primarily southeasterly, with northeasterly and westerly winds frequent as well. The magnitude of the wind sector "pie" slices indicate that the strongest winds are very strongly southeasterly.

Note that the measured wind rose at the met tower site mostly correlates with that winds observed by the automated weather station at the nearby Egegik Airport. The primary difference is that the airport recorded more northerly winds that was measured at the met tower.

Wind frequency and energy rose



Egegik Airport wind rose



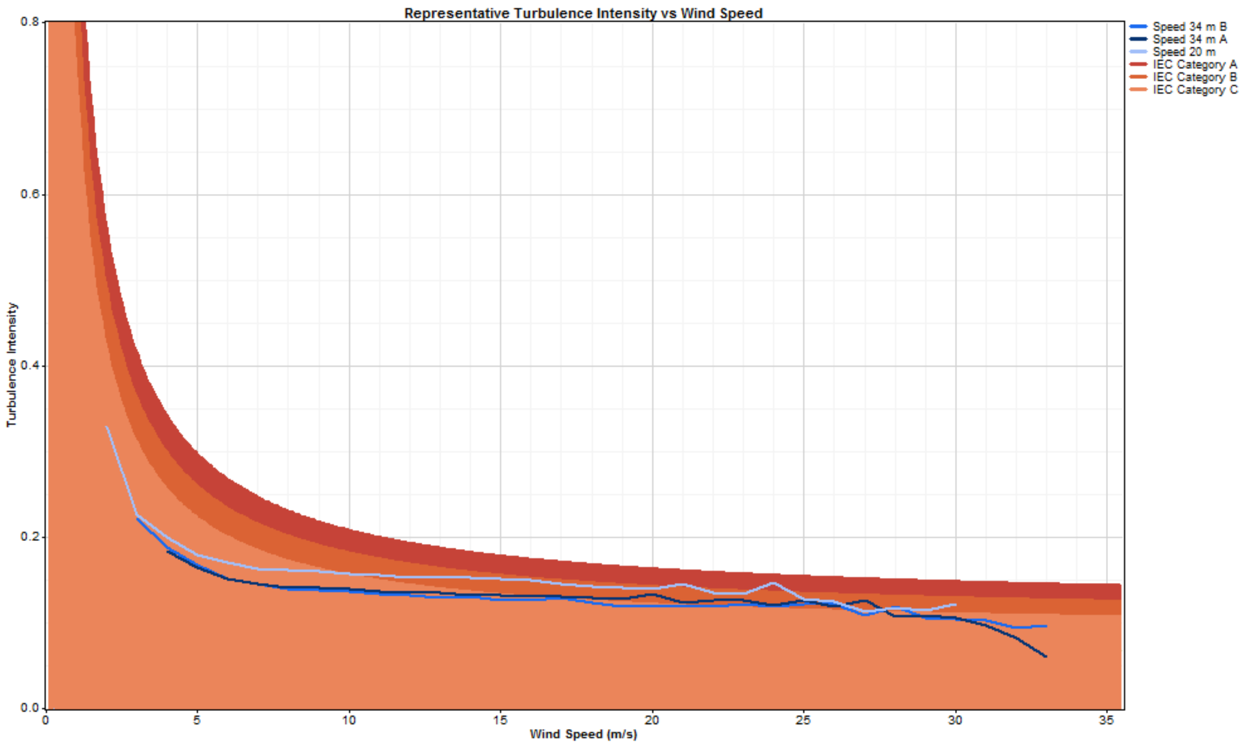
Turbulence

The turbulence intensity (TI) at the Egegik met tower site is low with a mean turbulence intensity of 0.075 and a representative turbulence intensity of 0.104 at 15 m/s wind speed at the 34 meter level, indicating smooth air for wind turbine operations. This equates to an International Electrotechnical Commission (IEC) 61400-1, 3rd Edition (2005) turbulence category C, which is the lowest defined category.

Turbulence Intensity table

	All Speed Bins				15 m/s Speed Bin			
Wind Speed Sensor	Mean TI	SD of TI	Representative TI	Peak TI	Mean TI	SD of TI	Representative TI	IEC 3 ed. Turb. Cat.
Speed 34 m B	0.130	0.090	0.250	1.46	0.104	0.018	0.127	C
Speed 34 m A	0.130	0.080	0.240	1.74	0.104	0.023	0.133	C
Speed 20 m	0.150	0.080	0.250	1.27	0.129	0.018	0.152	B

Turbulence intensity, all direction sectors



Appendix B – Bergey Excel 10 Manufacturer Information

Testimonials.

"I installed my Bergey 10 kW in 2001. I haven't paid an electric bill since and the turbine has paid for itself. It's the best investment I ever made." **G. Sansone, Oak Hills, CA**

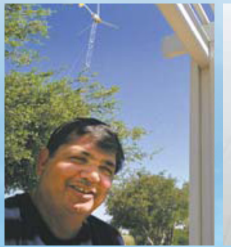
"I replaced a broken Whirlwind Power turbine with a Bergey 10 kW in 1988. I should have bought the Bergey in the first place."
R. Bohl, Phillipburg KS

"My first Bergey 10 kW installation has operated for over 26 years with insignificant maintenance costs and has had a 100% availability factor. It couldn't be more reliable."
S. Chase, Shokan NY.

"I made a big mistake when I used a Chinese turbine with an American sounding name. It just didn't hold up. What a difference in the Bergey equipment." **S. Jackson, Chico, CA**

Specifications.

Reference Rated Power: 10 kW.
AWEA Rated Power: 8.2 kW at 25mph.
AWEA Rated Annual Energy: 13,200 kWh at 11 mph average.
AWEA Rated Sound Level: 54.7 dBA.
Cut-in Wind Speed: 5 mph.
Cut-out Wind Speed: none.
Peak Power: 12.5 kW at 28 mph.
Max. Design Wind Speed: 135 mph.
Design Operating Life: 30-50 years.
Turbine Rotor Diameter: 23 ft.



Buying a Bergey turbine.

The best candidates for a Bergey 10 kW wind turbine are those with a residential or commercial property of at least 1 acre, an electric bill averaging over $150 per month, and a wind resource of at least 10 mph. Each project is a little different so a site survey and quotation are necessary. The typical steps in buying a Bergey wind turbine are:

1. Contact a local Bergey dealer. For assistance, see the Dealer Lists page at www.bergey.com.

2. Purchase a site survey from the dealer. Following the survey you will receive a quotation and a projection of performance and payback.

3. Purchase the system. Your Bergey dealer will apply for the necessary permits and available rebates, contact your utility company, get your Bergey wind equipment shipped, and provide you with a preliminary schedule for the work at your home or business.

4. Once the permits and equipment are in hand, your Bergey dealer will schedule your installation. This will involve several visits for foundations, wiring, and turbine installation.

Typically, getting the permits to install the 80 – 140 ft towers we recommend is the biggest obstacle you and your BWC dealer will face. Few cities or counties have ordinances that favor small wind turbines.

For information on the permitting issues we recommend the AWEA guide available at:
www.awea.org/smallwind/pdf/InThePublicInterest.pdf

You will also find additional information at:
www.bergey.com

Power your dream
with the wind

BERGEY
WINDPOWER
www.bergey.com

Why buy a small wind system?

A Bergey wind turbine is a smart investment that will lower your monthly expenses, increase your net worth, and help support American manufacturing jobs. At the same time it will help clean the air, slow climate change, and move us towards energy independence.

You will also enjoy watching your utility meter turn backwards and the lively interaction between the wind and your Bergey turbine. Finally, it will totally change your view of wind – you will start appreciating windy days.

For those fortunate enough to have a windy site of at least one acre, a Bergey wind system will be substantially less expensive than a comparable solar system, it will take up less space, and its performance won't degrade over time.

It's like buying vs. renting a home.

Over the next 10 years a typical homeowner or small business will pay $18,000 to over $50,000 in electric bills, at rates that often increase faster than inflation. When you choose a Bergey wind system you take the same monthly expense and invest it in a tangible asset. Once your Bergey turbine is paid off, you will enjoy more money in your pocket every month for the next 20 – 40 years.

A Bergey wind turbine is an excellent investment. It will typically provide a rate of return of 6% - 25%, much better than traditional investments.

Tax credits and rebates make it affordable.

Small wind turbines qualify for a 30% federal tax credit and, for businesses, accelerated depreciation. USDA grants are available for farmers, ranchers, and rural businesses. Many states offer additional incentives (see www.dsireusa.org). These incentives make owning a Bergey wind turbine surprisingly affordable.

Why a Bergey wind turbine?

Bergey Windpower is the oldest and most experienced manufacturer of residential-sized wind turbines in the world. Thirty years ago Bergey pioneered the radically-simple "Bergey design" that has proven to provide the best reliability, performance, service life, and value of all of the hundreds of competitive products that have come and gone in that time. With only three moving parts and no scheduled maintenance necessary, the Bergey 10 kW has compiled a service record that no other wind turbine can match. We back it up with the longest warranty in the industry.

There are now many new small wind products on the market. Though sometimes heavily promoted, these new entrants lack the track record that provides confidence as a sound investment. Over the years Bergey wind turbines have often replaced unsuccessful competitive products. The bottom line is that wind turbines are a big investment, and Bergey is the wise choice.

Bergey turbines are simple, but they also incorporate sophisticated technology that has been refined over more than a quarter-century. From its custom airfoil to its "super magnet" low speed alternator to its custom inverter, there's no more advanced technology in the industry. The result is exceptional low wind speed performance, robust storm protection, and almost silent operation.

Finally, Bergey offers more tower options than any other small turbine manufacturer. We have Guyed-Lattice, Self-Supporting Lattice, Tubular Self-Supporting, and Guyed Tilt-up Lattice towers in heights from 60 ft to 160 ft.

Bergeys are built on strong basics:

Simplicity:
The only moving parts are the parts you see moving.

Reliability:
Developed in "Tornado Alley", proven in critical military applications, and backed by our exclusive 10-year warranty.

Performance:
Low start-up(5 mph), continuous operation in high winds, and extremely quiet.

Our technology makes it happen!

PowerFlex Blades
Our exclusive "full length reinforcement" fiberglass blades are stronger than steel and the strongest in the industry.

BW-7 Airfoil
Our custom designed airfoil (blade shape) is quieter and more efficient than the "catalog airfoils" others use.

Neo-10 Alternator
Our custom designed very-low-speed "super magnet" alternator also serves as the blade mounting hub, integrating what are typically two seperate assemblies.

AutoFurl Storm Protection
Our uniquely simple passive, fully automatic, high wind protection is hurricane proven.

Powersync II Inverter
Our custom designed third-generation power converter is UL-certified and extremely rugged.

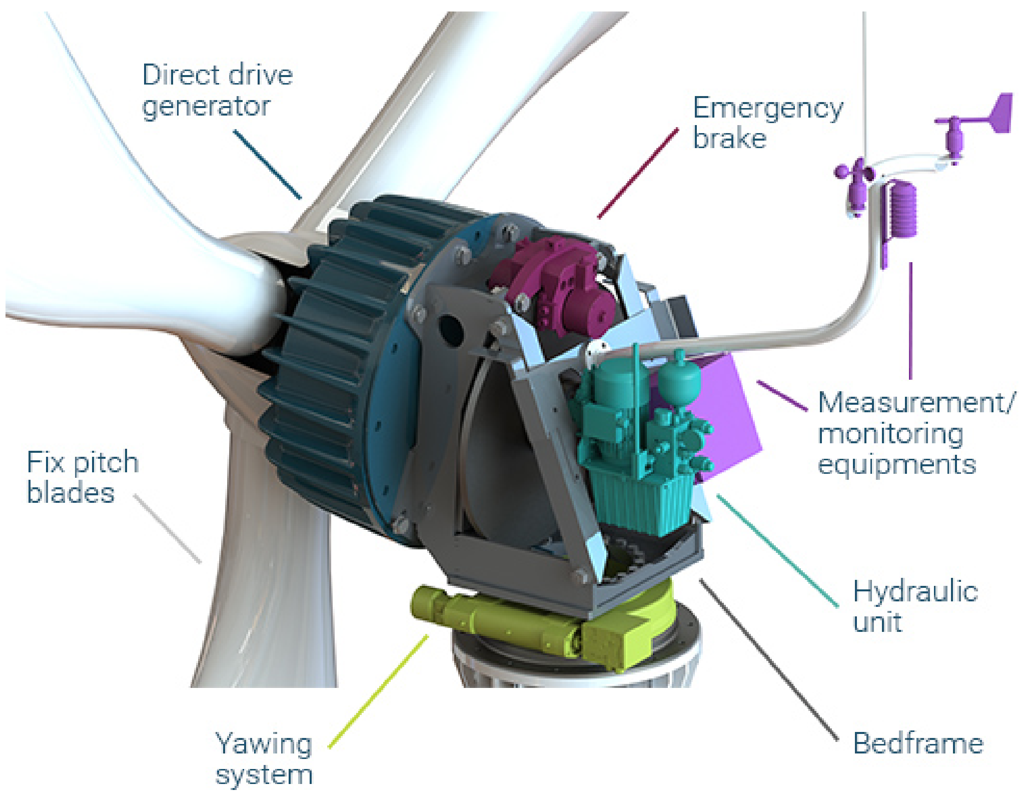
Appendix C – EOCycle EO25 Manufacturer Information

eocycle

Home » Our Wind Turbines

OUR SMALL WIND TURBINES

Eocycle's technology combines versatility and a pioneering spirit in order to offer proven products of superior quality.



+ Get a Free Evaluation!

The solution for distributed energy production

Our direct drive EO20 and EO25 wind turbines are equipped with a patented permanent magnet generator, fixed-pitch blades and a flexible coupling to eliminate problems related to gearboxes and blade-pitching systems. Eocycle holds patents in North America, Europe and China.

They also benefit from a self-monitoring system, protections against lightning and corrosion, as well as the best components in their category. They originate from the most renowned suppliers of the well-proven large wind turbine industry.

Eocycle turbines generate more energy over longer periods of time.

WHY CHOOSE EOCYCLE

Summary of characteristics

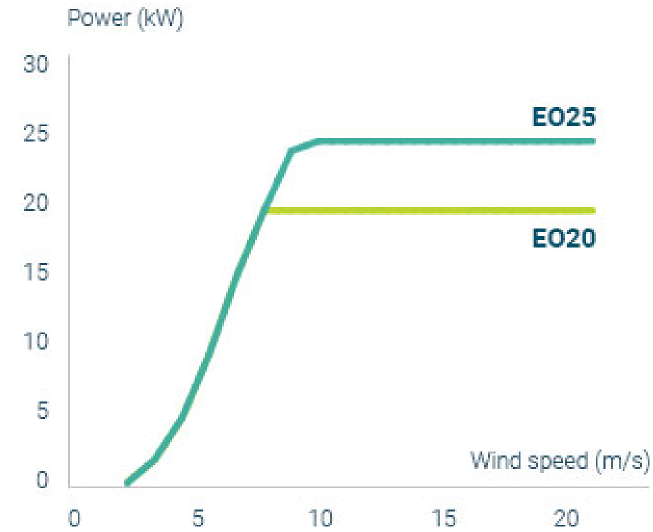
	EO20	EO25
DESIGN STANDARD	IEC 61400-2 Wind Class III	
DESIGN LIFETIME	20 years min. (without major component replacement)	
RATED POWER	20 kW	25 kW
CUT-IN WIND SPEED	2.5 to 3 m/s	
CUT-OUT WIND SPEED	20 m/s	
EXTREME WIND SPEED	52.5 m/s (3-sec. average)	
LIGHTNING PROTECTION	Lightning rod on nacelle	

To obtain the complete specifications of our wind turbines:

CONTACT OUR TEAM

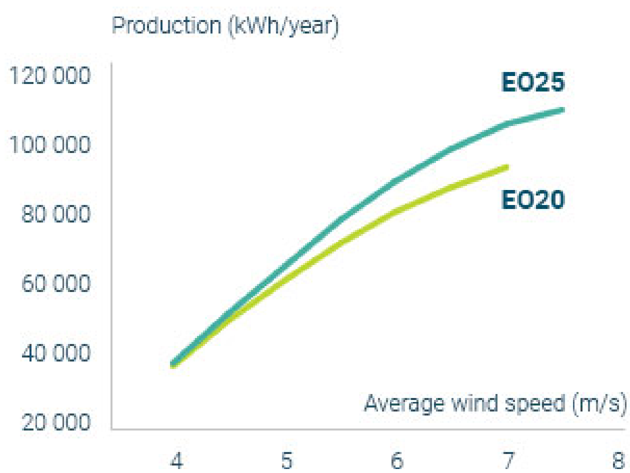
+ Get a Free Evaluation!

Power curve



Note : The theoretical power curve is calculated for standard air-density of 1.225 kg/m³ (sea level at 15ºC).

Annual energy production



Note : The theoretical production is calculated according to a Weibull distribution with a factor of k=2 and for a standard air-density of 1.225 kg/m³ (sea level at 15ºC).

Generate a **significant financial performance** with our hassle-free wind turbine solutions.

MAKE MONEY WITH THE WIND

+ Get a Free Evaluation!

Flexible and adaptable

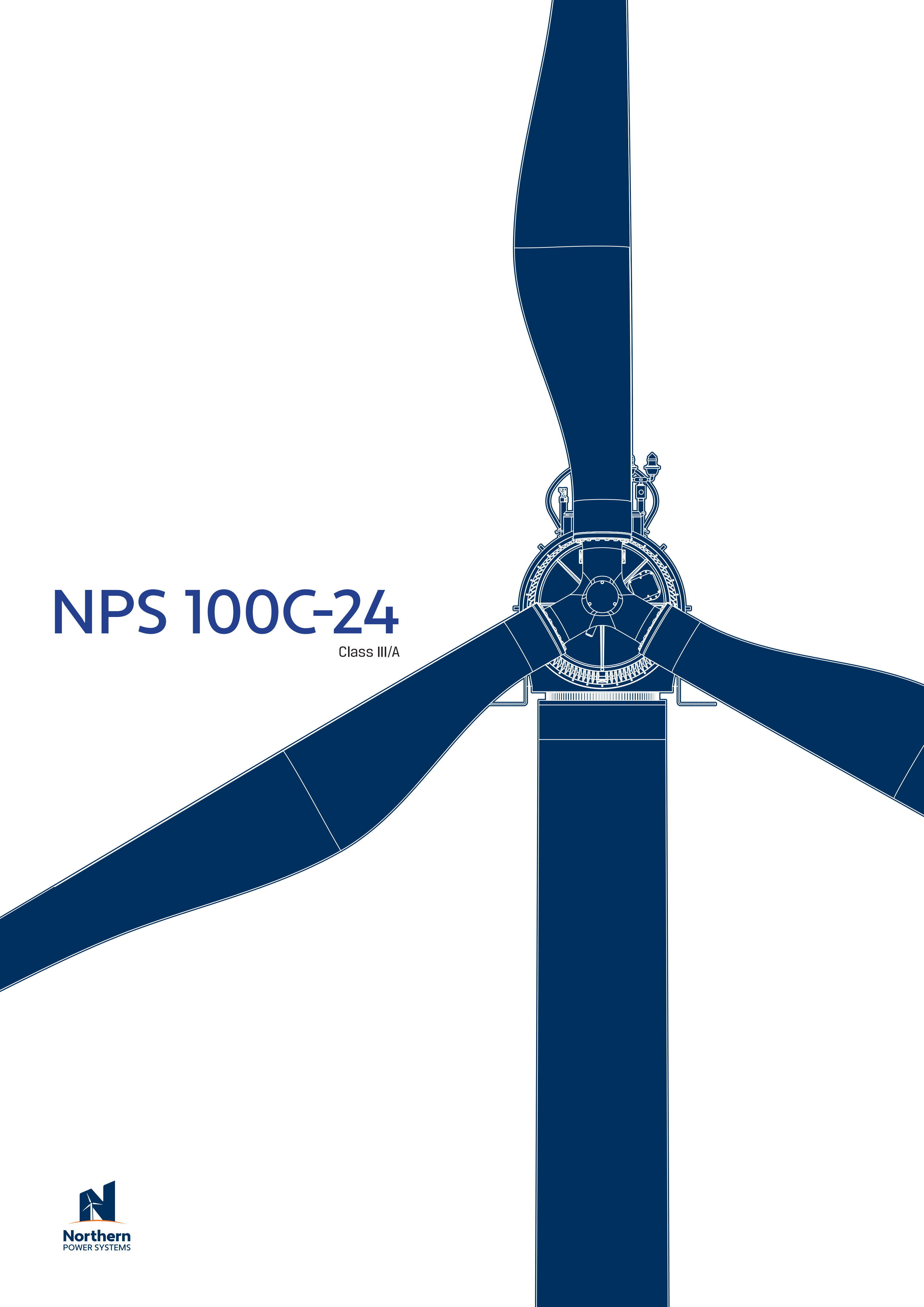
Reconcile regulatory compliance of your locality and capacity limit for the connection to the network, thanks to the variable speed of our wind turbines. The electronic and adaptive management of their power ensures easy connection to the electricity network and a **maximum production of energy in all conditions**.

Also, take advantage of their rugged construction which makes it possible to install them in areas of high wind resources and cope with gusts of up to 52.5 m/s. A **northern version** of our wind turbines can withstand temperatures as low as -40°C.

Patented hydraulic system

Save substantial sums on installation, maintenance, or in case of excessive weather conditions, with the patented climbing-step system that makes it possible to climb and descend the n

Appendix D – Northern Power System NPS100-24 Manufacturer Information



NPS 100C-24

Class III/A

Northern
POWER SYSTEMS

The Next Generation High Output Wind Turbine for Low Wind Regimes

NPS 100C-24

Class III/A

» Introducing the NPS 100C, the next generation of our industry leading permanent magnet/ direct drive distributed wind turbines.

» A new 24-meter rotor features state-of-the-art hub and blade technology with superior aero-dynamics providing a larger swept area. This increases the annual energy production (AEP) of the NPS 100C-24 by 11% over the previous model.

» The turbine is a complete redesign of NPS' distributed wind platform that has been deployed around the world since 2008. The nacelle is now 30% smaller with a completely new tower configuration. This results in lower weight and load characteristics reducing foundation and installation costs.

» Further improvements include a new best in class brake system, a new industry leading yaw configuration, an enhanced electrical layout, more efficient generator cooling, and an ultrasonic wind vane and anemometer.

» Over 5 million hours of cumulative run time makes the NPS 100 turbine series one of the most reliable and proven wind turbines in the world. The average availability of Northern Power's global fleet currently stands at 99.5%.

» This is made possible through an engineering advancement in simplicity and precision. Our permanent magnet direct drive (PMDD) technology maximizes energy capture, outperforms conventional gearbox designs, and reduces maintenance costs.

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POWER SYSTEMS

Specifications

General Configuration

Model	Northern Power® 100C-24
Design Class	IEC WTGS III/A air density 1.225 Kg/m³, average annual wind below 7.5 m/s (17 mph), 50-yr peak gust below 52.5 m/s (117 mph)
Design Life	20 years
Rotor Diameter	24.4 m (80 ft)
Tower Types	Tubular steel monopole
Hub Height	37 m (117 ft), 29 m (93 ft), 22 m (69 ft)
Orientarion	Upwind, 3 blade
Yaw System	Active yaw drive with wind direction/speed sensors and automatic cable unwind
Power Regulation	Variable speed, stall control
Certification	CE compliant, CEI 0-21

Performance

Rated Wind Speed	12 m/s (27 mph)
Cut-in Wind Speed	3 m/s (7 mph)
Cut-out Wind speed	25 m/s (56 mph)
Extreme Wind Speed	52.5 m/s (117 mph)

Weight

Rotor (24 m) & Nacelle	6,900 kg (15,200 lbs)
Tower (37 m)	12,000 kg (26,500 lbs)

Drive Train

Gearbox Type	No gearbox (direct drive)
Generator Type	Permanent magnet

Braking System

Redundant Braking System (per IEC 61400-1ed3)	Generator dynamic brake and multiple hydraulic calipers

Control System

Controller Type	DSP-based multiprocessor embedded platform
Converter Type	Pulse-width modulated IGBT frequency converter
Monitoring System	SmartView® remote monitoring system, ModBus TCP

Electrical System

Rated Electrical Power	95 kW, 3 Phase, 480 VAC, 60H
Power Factor	Set point adjustable between 0.9 lagging and 0.9 leading
Reactive Power	+/- 45 kVAR
Grid Interconnect	Utility approved protective relay included

Noise

Apparent Noise Level	50 dBa at 50 meters from nacelle (164 ft)

Environmental Specifications

Temperature Range Operational	-20°C to 40°C (-4°F to 104°F)
Temperature Range Storage	-30°C to 50°C (-22°F to 122°F)
Lightning Protection	Receptors in blades, nacelle lightning rod and electrical surge protection

Key Benefits

» **Optimized for lower wind regimes**
The NPS 100C-24 starts making power at wind speeds as low as 3 meters per second (6 mph) and provides maximum generation at 12-15 mps (25-34 mph)

» **Reliable**
Reinforced blades, gearless design, industry leading yaw configuration, and best-in-class brake system make Northern Power turbines the most reliable small wind turbines available today

» **Easier permitting**
The NPS 100C-24 comes with 22, 29 and 37-meter tubular tower options to meet local tip height restrictions. The low noise profile and new color minimize the acoustic and visual impact for easier permitting

» **Low ownership cost**
With low ownership costs over the lifetime of the turbine, the NPS 100C-24 pays for itself quickly and will generate reliable power over its 20+ year life

» **Plug and play**
Our state of the art power converter design provides smooth, clean power to local grids, which simplifies grid connection

2 Year Warranty

The NPS 100C-24 is covered by a 2-year manufacturer warranty. This covers parts, labor and freight in the unlikely event something were to go wrong. Other services in the Northern Power warranty include:

- **24x7 monitoring and reporting:** Operation teams in the UK, Italy and the United States oversee the performance and operation of your wind turbine to ensure maximum availability
- **Global Spares Management Program:** New parts for the NPS 100C-24 dispatched for same-day or next-day delivery

Extended O&M Contract

Extended operations and maintenance is available direct from Northern Power Systems once the warranty ends. Dependent on the terms agreed our engineers will continue to provide:

- Monitor and reporting
- RTU maintenance
- Remote support
- Preventative maintenance

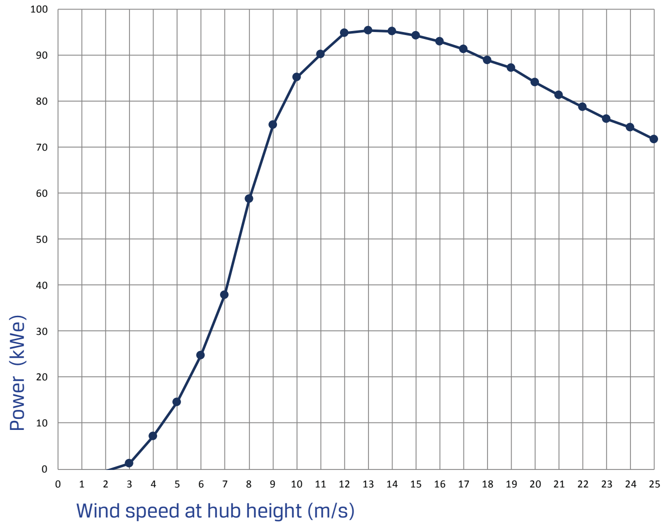
Power Curves

NPS 100C-24 Class III/A Power Curve

24m Rotor, Standard Conditions*

wind speed (m/s)	1	2	3	4	5	6	7	8	9	10
electric power (kWe)	-0.5	-0.5	1.2	7.2	14.5	24.7	37.9	58.7	74.8	85.1

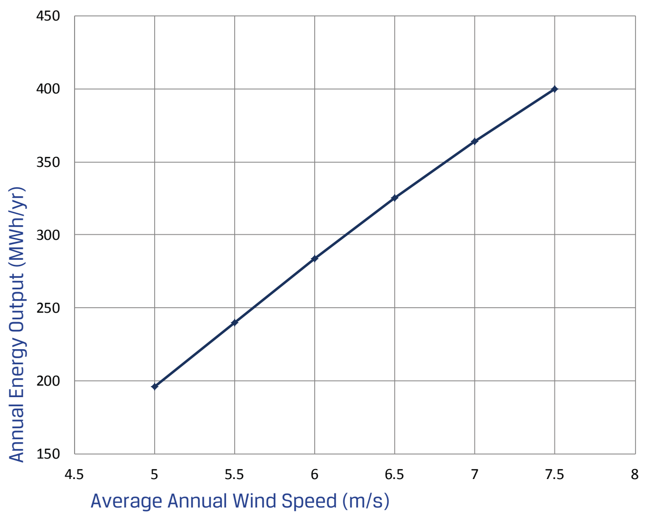
11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
90.2	94.7	95.3	95.1	94.2	92.9	91.2	88.9	87.1	84.1	81.3	78.6	76.1	74.3	71.7



Annual Energy Production: 24-Meter Rotor

Standard Conditions,* Rayleigh Wind Distribution

		11	12	13	14.5	16	17
	(mph)	11	12	13	14.5	16	17
Average annual wind speed	(m/s)	5.0	5.5	6.0	6.5	7	7.5
Annual energy output	(MWh/yr)	196	240	284	325	364	399



* Standard conditions: air density of 1.225 kg/m³, equivalent to 15°C (59°F) at sea level

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Appendix E – XANT M-24 Manufacturer Information

XANT

WIND POWER MADE EASY

XANT M-24 (95 kW) - Class III^{A}

XANT N.V. | Vaartstraat 63 - 65, 1000 Brussels, BELGIUM
Tel. + 32 56 707 055 | info@xant.com | www.xant.com

WIND TURBINE RATING

Rated electrical power	95 kW
Power factor	0.9 inductive - 0.9 capacitive
Cut-in wind speed	3 m/s
Survival wind speed	52.5 m/s
Electrical output	400 VAC, 50 - 60 Hz

GENERAL CONFIGURATION

Rotation axis	Horizontal
Rotor Orientation	Downwind
Rotor Diameter	24 m
Number of blades	3
Drive train	Direct-drive permanent-magnet generator
Converter	Full-power electronic converter

SAFETY & CONTROL SYSTEMS

Power regulation	Variable speed, stall with aeroelastically-tailored blades
Braking systems	Electrical brake and electromechanical brake
Monitoring system	Webbased HMI
Controller	Industrial PLC

PRODUCT MASS & FOOTPRINT

Tower top mass	7.5 tons
Total mass	14 tons (stand-alone tower)
Footprint	+/- 15 m^2 (stand-alone tower)
Concrete volume	50 m^3

CERTIFICATIONS

Turbine Class	IEC 61400-1 Class III^{A}
Certification	Design compliance by DNV-GL

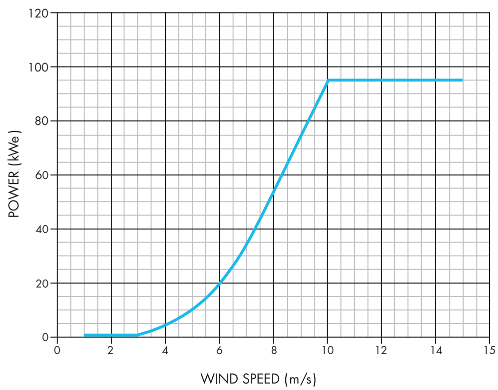
TOWER

Type	Tubular stand-alone or tubular guyed tower
Hub height	23 / 31.8 / 38 m *

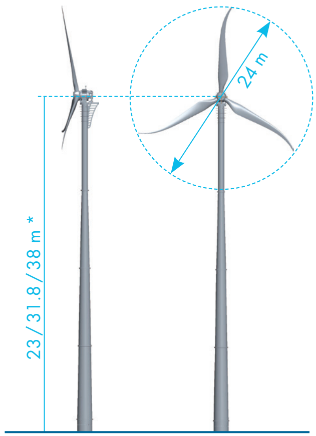
TRANSPORT AND INSTALLATION

Transport	standard 40 ft OT container
Erection	Gin pole with reeving systems or crane

POWER CURVE



Average Wind Speed (m/s)	Annual Energy Yield (MWh)
3.0	41.4
3.5	69.0
4.0	104.0
4.5	146.0
5.0	188.7
5.5	234.0
6.0	278.6
6.5	321.1
7.0	360.3
7.5	395.6



* other heights available upon request